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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
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Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 12, NO. 1, PP. 3–9, FIGS. 1–5, TABLE 1, APRIL, 1942

SEDIMENTATION NEAR JUNCTION OF MAQUOKETA AND MISSISSIPPI RIVERS

FRANK A. SWENSON
University of Iowa, Iowa City, Iowa

ABSTRACT

Sediment samples indicate that the Maquoketa River has been, in the past, an important factor in the deposition that has taken place in the Mississippi River in a reach extending at least 4½ miles below the junction of these streams. It is believed that the straightening of the tributary stream was an important factor in the increased deposition between 1930 and 1937 Computations show that in the reach of river studied approximately 30 per cent of the sediment was derived from the Maquoketa River.

INTRODUCTION

The Maquoketa River enters the Mississippi near the extreme eastern portion of Iowa, about 7 miles downstream from Bellevue, and about 10 miles above Sabula, Iowa. The present study is based on 101 sediment samples collected from the lower 8 miles of the Maquoketa River and from a reach of the Mississippi River extending from 1½ miles above to 4½ miles below the junction of the rivers. The area studied lies in Jackson County, Iowa, and in the Mississippi River which forms the boundary between this county and Carroll and Jo Daviess Counties, Illinois. The location of the area is shown in figure 1.

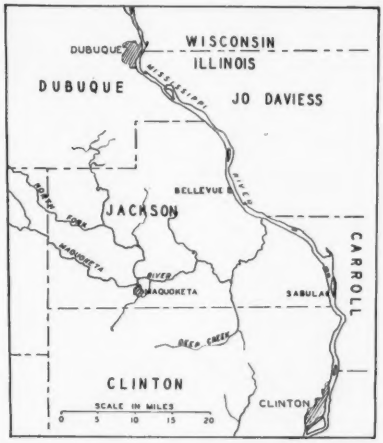


FIG. 1.—Map showing location of area studied.

ACKNOWLEDGMENT

The samples for this investigation were taken by the writer, while he was employed by the U. S. Engineer department in a channel survey. The sampling was done in the late summer and early fall of 1939. After the samples had served the purpose for which they were taken, permission to use them in this investigation was granted by the District Engineer Lt. Col. E. E. Gesler, with the stipulation that the findings would be made available to the U. S. Engineer Office, Rock Island, Illinois.

Thanks are due to Lt. Col. Gesler and also to Dr. A. C. Trowbridge under whose direction the investigation was carried out.

The analysis of the samples was made in the Sedimentation Laboratories of the Geology department of the State University of Iowa, during the academic year of 1939–40.

STATEMENT OF PROBLEM

The problem being investigated had its inception with the straightening of the lower 7.5 miles of the Maquoketa River in 1930–31. Previous to that time, the

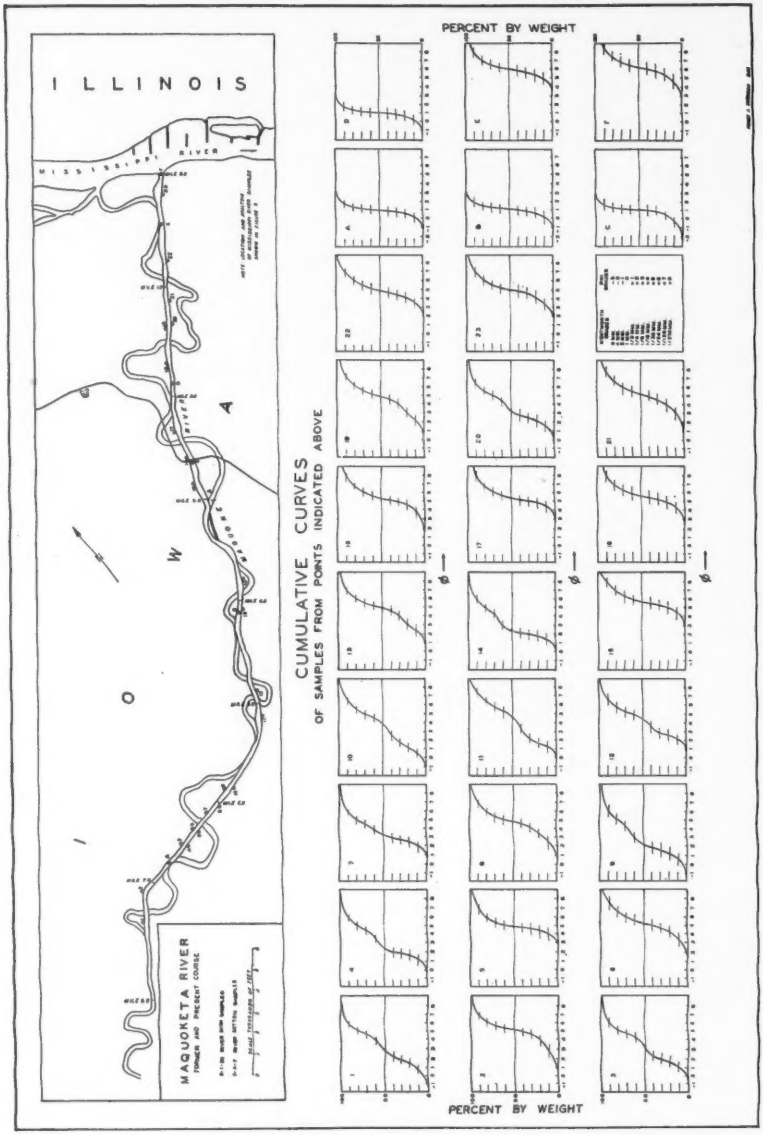


FIG. 2.—Map of Maquoketa River showing the former and present courses. Sampling stations and cumulative curves of sediment samples shown also.

river had flowed in a meandering course across a partly dissected valley fill of late Wisconsin age. Well developed stream terraces, some 50 feet above the present flood plain, give evidence of the amount of erosion that has gone on since the deposition ceased. The filling of the ancient valley was due to the partial ponding of the ancestral Maquoketa behind the valley-train formed in the Mississippi River from the glacial materials contributed by the glacial lobes of Mankato age in the vicinity of St. Paul, Minnesota (Trowbridge and Shaw). The streams have been prevented from completing the excavation of their former valleys by the rock sill across which the Mississippi River was superposed from Cordova, Illinois to Muscatine, Iowa.

The Maquoketa River, judging by the width of the flood plain, had been at grade for a considerable time previous to the straightening. This valley flat was subject to floods, due in part to the inability of the stream to discharge flood waters through the tortuous series of meanders at a rate equal to that of the steeper, straighter portions of the upper river.

The project of straightening the Maquoketa River was planned to help prevent these floods and to make it cheaper to build and maintain levees along the lower portions where the flood plains of the Maquoketa and Mississippi Rivers merge. The former and present courses of the tributary stream are shown on the map of figure 2.

The river was straightened by means of diversion ditches cut across the necks of the meanders. These ditches were cut with 12-foot bottoms and sides sloping 60 degrees, the latter enabling the bank to slump and widen the ditch. Since the time these ditches were cut, they have increased in width until they now are 150 to 250 feet wide. At present there are no constrictions in the channel to indicate the positions of the straightened portions. The presence of ox-bow lakes and somewhat steepened banks are the only indications now found of the diversion ditches.

The straightening, and thus shortening, of the Maquoketa River caused an increased gradient, and with it an increased carrying power. These factors aided the river in accomplishing the task of widening the original diversion ditches. The materials which have been eroded out were contributed to the Mississippi River's load. The lower gradient of the main stream, along with the increased load, caused deposition to take place in the channel of the main river. This deposition obstructed the navigation channel of the Mississippi River to a considerable degree.

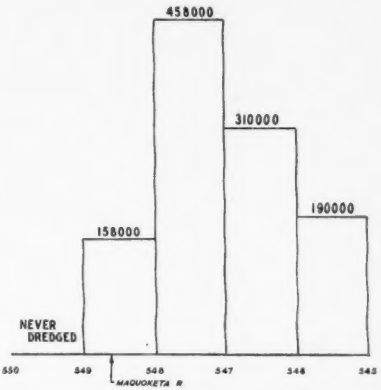


FIG. 3.—Graph showing cubic yards of sediment dredged from the Mississippi River channel. Miles above mouth of the Ohio River shown.

In order to maintain a navigable channel, the U. S. Engineer Department was obliged to dredge a large amount of material from the channel. Figure 3 shows the approximate quantities of sediment dredged for each mile of the reach of river most affected. A breakdown of these same data into years is shown in figure 4. The largest amount of deposition took place two years after completion of the project, and deposition is steadily de-

creasing. The effect of the increased gradient of the Maquoketa River has largely been eliminated by the backwater from the Mississippi River navigation dam at Clinton, Iowa. This dam was placed in operation during May, 1939. Due partly

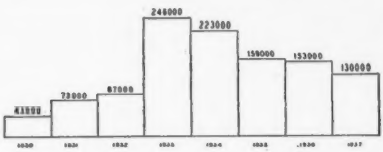


FIG. 4.—Graph showing cubic yards of sediment dredged from Mississippi River from reach shown above, for each of eight years, 1930 to 1937 inclusive.

to decreased deposition, and partly to somewhat higher river conditions, there has been no dredging in this reach of the river since 1937.

PURPOSE OF STUDY

The purpose of this study was to determine the types of sediments that were being carried, and deposited, by these rivers under present conditions. It was also planned to determine what per cent of the total sediment deposited by the Mississippi River, in the 4½ miles below the mouth of the Maquoketa, had been contributed by the latter stream.

MAQUOKETA RIVER DRAINAGE BASIN

Areal Extent.—The drainage area of the Maquoketa River is about 1900 square miles in extent. The river heads on the surface of the earliest Wisconsin glacial drift, the Iowan, near the town of Oelwein, Iowa, The stream measures less than 150 miles in length, and in this distance, it drops about 600 feet for an average gradient of 4 feet to the mile. The gradient in the lowermost 8 miles, the area studied in this investigation, is approximately 2 feet to the mile.

Land Use.—Much of the drainage area of the Maquoketa River is cultivated, but some of the steeper sections are kept in permanent pasture and timber. The soil types are varied, being derived largely from the weathering of the glacial drifts and the loess.

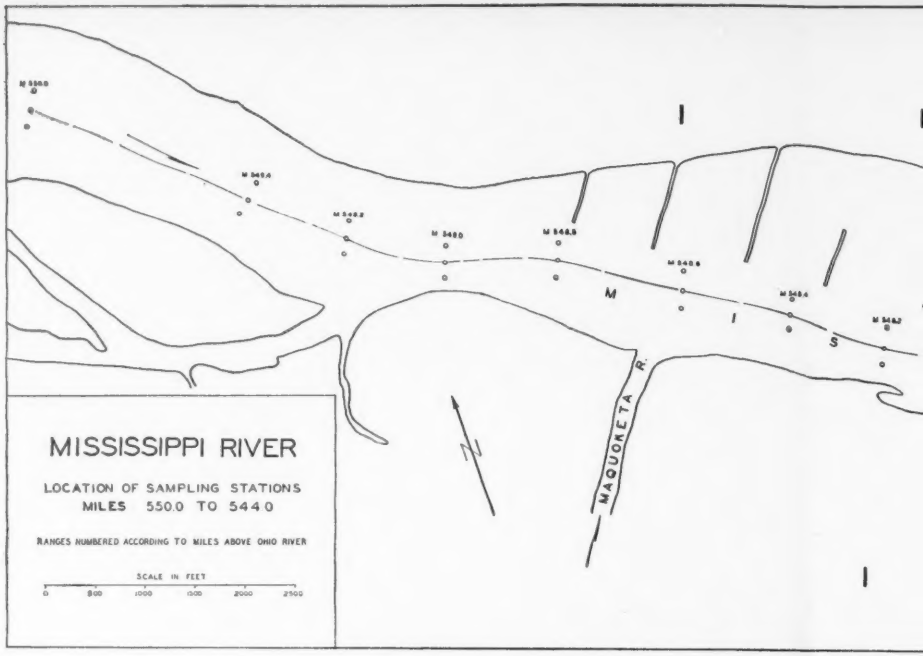
Topography.—Much of the drainage basin of the Maquoketa River has a loess mantled erosional topography (Kay and Apfel). The maximum relief of the area is almost 400 feet. Except for minor areas at the extreme headwaters, where early Wisconsin (Iowan) glacial drift is present, the Maquoketa drains a region covered by Kansan glacial drift. The total relief of the mature erosional surface of this drift is somewhat increased by the mantle of loess.

Bedrock Geology.—The drainage basin of the Maquoketa River is underlain by rocks of Silurian and Ordovician ages, the Maquoketa shale of the latter being found only along the lowermost 10 miles of the course. The outcropping of the shale in this position has been an important factor in the widening of the lower valley of the Maquoketa. The widening has taken place by the removal of the shale from under the resistant Silurian dolomites. Aside from the immediate river valley, the bedrock is exposed in relatively few places, due to the heavy mantling of glacial drift and loess.

FIELD METHODS

River Bottom Sampling.—Seventy-two of the samples were obtained from the bottom of the Mississippi River, and six from the bottom of the Maquoketa River. The dredge used consisted of an eight-inch section of 3.5-inch boiler tubing with a solid bottom welded on. The stem was fastened to a swivel joint in the center of the bottom, so that comparable samples might be taken regardless of the position of the sampler on the bottom. The sampler was operated on the end of a light cotton line, the length of line varying with the depth of the water. In general practice enough line was played out so that an angle of 45 degrees was formed by the line and the water surface.

Samples were taken from the bottom of the Mississippi River along 24 ranges, varying from 0.2 to 0.6 miles apart, de-


M 550.0
M 549.4
M 549.2
M 549.0
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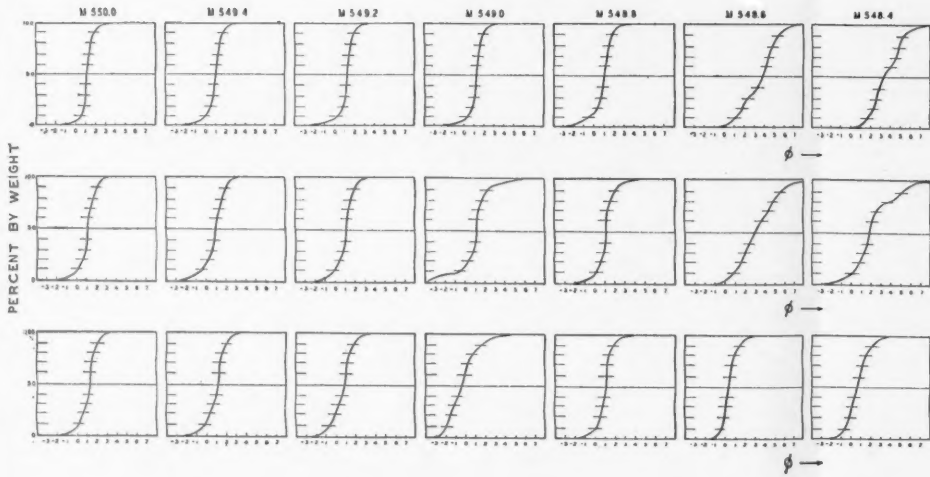
I
S
MAQUOKETA R.
MISSISSIPPI RIVER
LOCATION OF SAMPLING STATIONS
MILES 550.0 TO 544.0
RANGES NUMBERED ACCORDING TO MILES ABOVE OHIO RIVER
SCALE IN FEET
0 500 1000 1500 2000 2500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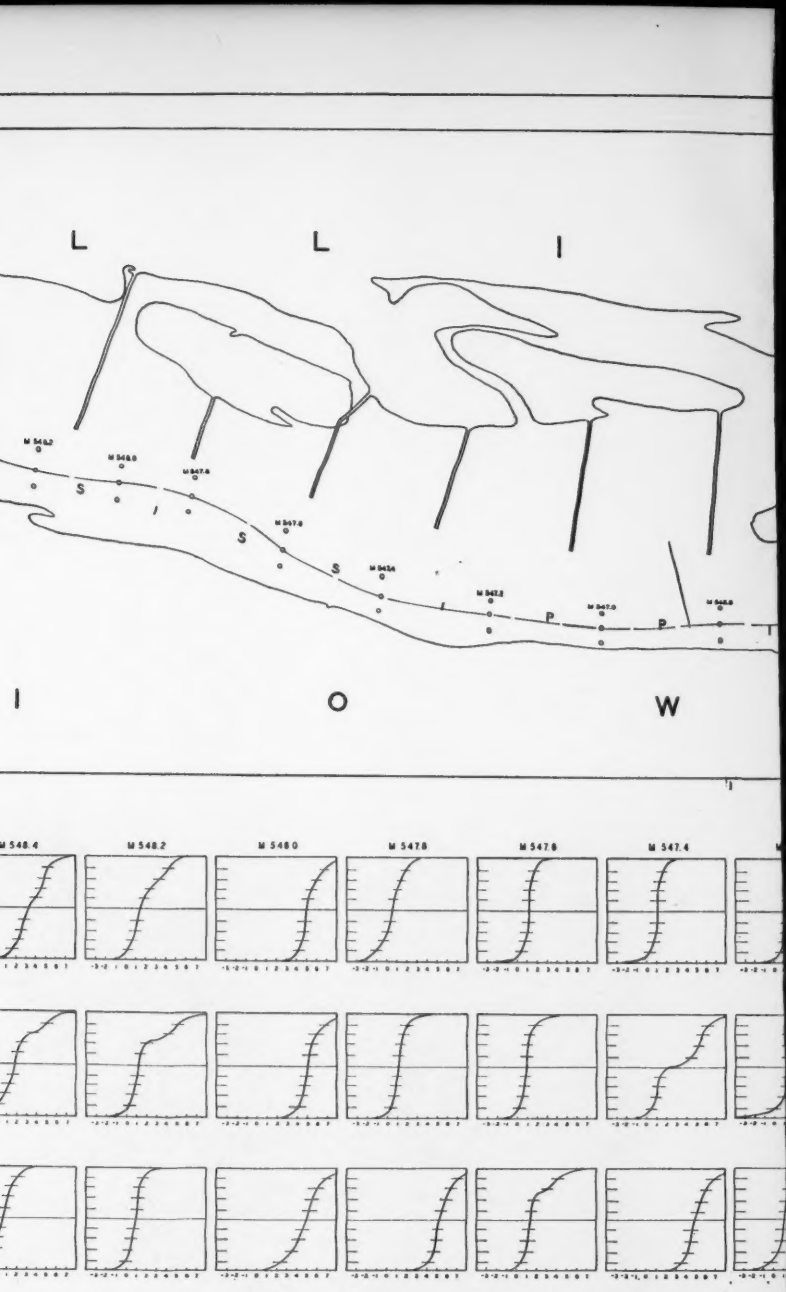
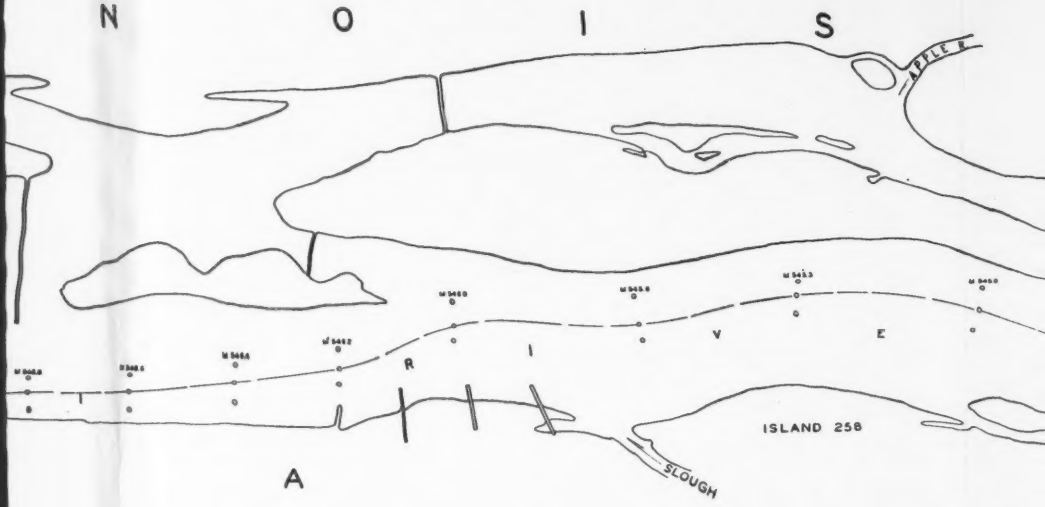
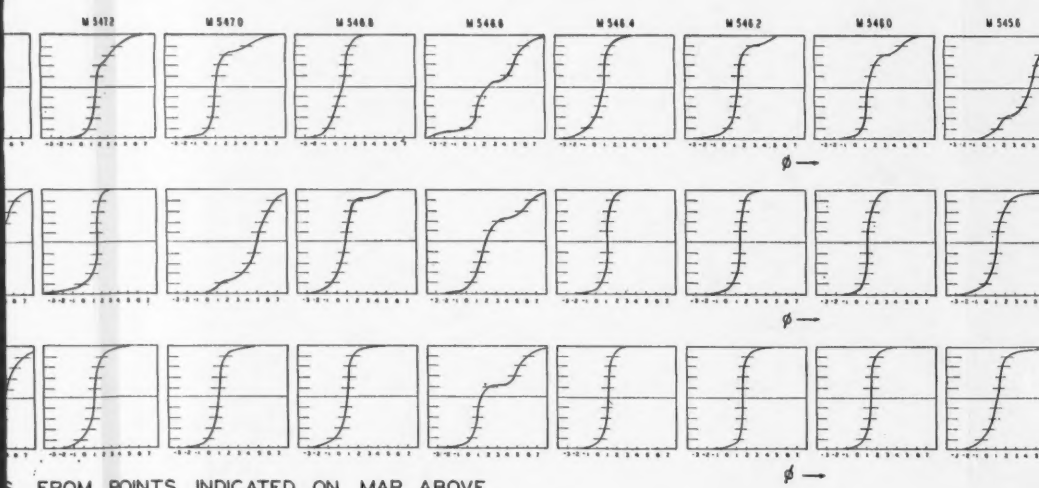


CUMULATIVE CURVES OF SAMPLES FROM

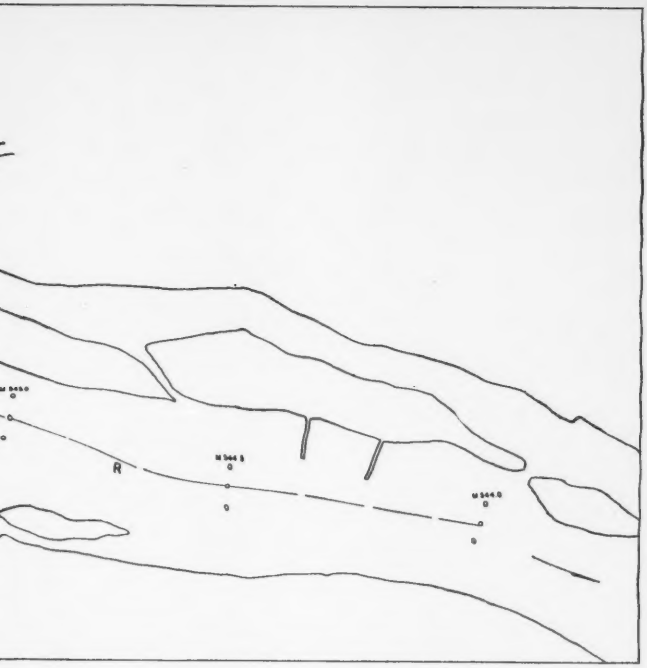
FIG. 5.—Map of Mississippi River sampling stations. Cumulative curves show

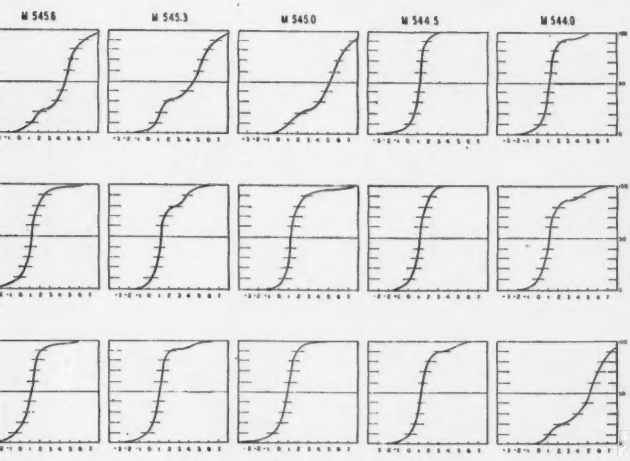




S FROM POINTS INDICATED ON MAP ABOVE

urves show size-grade distribution of samples collected from each station.





FRANK A. SHEVSON 1940

pending on the expected importance of the range. The ranges were laid out by means of chained traverses along the banks, they were prominently marked by means of two flags set in a line normal to the current flow. Three samples were taken on each range, one in the center of the channel and one on either side at a distance of 150 to 200 feet from the first. The locations of the sampling stations are shown in fig. 5. The distances from shore, on the ranges, were determined by stadia readings and the stations were plotted on the plane-table sheets which served as base maps. The ranges are numbered according to the miles above the mouth of the Ohio River.

The samples were taken from a U. S. Engineer Department launch. After the boat had been maneuvered into position the sampler was lowered and filled as the boat drifted with the current. It is not believed that the sampler penetrated more than an inch into the bottom material. It was found that if the line was held taut the sampler would be three-fourths filled after dragging about 5 feet. The samples were placed directly in one-quart Mason jars.

The samples from the bottom of the Maquoketa River were taken with the same sampler, but due to the shallowness of this stream, an outboard motor-boat was used. Two of the samples were taken from bridges by tossing the sampler out and dragging it back to fill.

The depths at which the Mississippi River bottom samples were taken varied from 10 to 35 feet, these depths being determined by means of a sounding pole or weighted cable. The depths and locations of points sounded were spotted by an alidade and plotted directly on the plane-table map set up on shore. In this way, accurate knowledge of the bottom configuration of the river was obtained.

River Bank Samples.—A total of 23 samples was taken from both sides of the Maquoketa River in the reaches which had been straightened. Elongated channeled samples were taken in order to obtain information about the average characteristics of the materials involved in the widening of the diversion ditches. In most places, a steep bank was found which was suited admirably for taking this type of sample. Where the banks were slumped, the material was removed with a spade to avoid a repetition of the upper layers.

LABORATORY METHODS

After drying the samples in the laboratory, they were halved with a Jones sample splitter until reduced to less than one hundred grams each. The amount of sample analysed varied, depending on the size of the particles and estimated degree of sorting.

The weighed sample was then sieved for 18 minutes with a Ro-tap machine in a nest of Tyler woven wire screens giving the Udden-Wentworth grades. The separated fractions were then weighed and their percentage of the entire sample computed.

Where more than five per cent of the total sample reached the pan, further divisions according to size were made by use of the standard pipette method as outlined by Krumbein (1932). By inspection, it was found that complete dispersion was obtained by soaking the sample in a N/100 sodium oxalate solution for 24 hours before starting the analyses; this practice was followed for all samples analysed by the pipette method.

PRESENTATION OF DATA

The size grade distribution of the samples, as determined by the analyses, is presented in the cumulative curves of figures 2 and 5. These curves are plotted using the 'phi scale' of Krumbein, since it allows direct application of the data to statistical methods of comparison. The curves are numbered to agree with the locations as shown on the maps across the tops of the figures.

COMPARISON OF SEDIMENTS IN TERMS OF DIMENSIONS

Samples for this investigation were taken from three distinctly different en-

vironments, as follows: *a*—Mississippi River above the mouth of the Maquoketa, *b*—The banks of the Maquoketa River itself, and the *c*—Mississippi River below the mouth of the Maquoketa.

The average size grade distribution of the sediments taken from all three of these distinct environments, and the computed sample are presented in table I.

TABLE I

Diameter in Millimeters	*a* %	*b* %	*c* %	*d* %
16–8	.3		.1	.2
8–4	1.8		.7	1.2
4–2	4.0	.2	1.6	2.9
2–1	7.9	.4	4.9	5.6
1–1/2	29.6	2.7	20.4	21.2
1/2–1/4	49.7	11.3	39.9	38.2
1/4–1/8	5.8	11.9	6.6	7.7
1/8–1/16	.7	6.8	3.0	2.6
1/16–1/32		23.7	9.7	7.2
1/32–1/64		24.6	7.6	7.4
1/64–1/128		9.2	3.1	2.8
1/128–1/256		4.9	1.3	1.5
1/256 . . .		4.3	1.1	1.3

Average size grade distribution of sediments from,
a—Mississippi River above mouth of Maquoketa,
b—Maquoketa River banks,
c—Mississippi River below the mouth of the Maquoketa,
d—Computed sample with 30% from Maquoketa and 70% from the Mississippi River.
Column *a* is based on the average of 15 samples, *b* of 23 samples, and *c* of 57 samples.

The most noteworthy characteristics of the sediments taken from environment *a* is their coarseness, and the fact that their size grade distribution indicates that they are lags left behind by the removal of much of the finer materials. The outstanding characteristics of the sediments from the banks of the Maquoketa River are their comparative fineness and the fact that there are two distinct maxima, one centered at about ¼ millimeter and the main one at about 1/32 millimeter. Column *c* of the table, which gives the size grade distribution of the sediments taken from the bottom of the Mississippi River below the mouth of the Maquoketa, shows the influence of the mixing of the sediments from the other two environments, the Mississippi and the Maquoketa Rivers.

By comparisons of curves plotted from the data presented in this chart, and simple calculations, it was determined that approximately 30 per cent of the materials deposited in the Mississippi River below the mouth of the Maquoketa (in the reach studied) were derived from the tributary stream. Column *d* is the calculated sample, assuming that equal per cents from each of the contributing streams remains in suspension and is removed from the locality. This assumption may not be completely justified, due to the differences in the size of the particles involved, yet a comparison of the calculated sample and the collected sample does not reveal any great deviation. Differences as great as those indicated here may be expected between two samples collected from the same locality.

The samples for this investigation were collected after a period of over a year in which neither of the streams had reached excessively high stages. This may possibly be an important factor in the close agreement found between the collected sample from environment *c* and the calculated sample. If either stream had experienced a flood stage shortly before the samples were collected, the findings may have been somewhat different. It is believed that the conditions were exceptionally favorable for an investigation of this type.

The fact that a state of equilibrium had been reached in the lower portion of the Maquoketa River is brought out by a study of the sediments now found in the bottom of the stream. Since the Mississippi River navigation dam at Clinton, Iowa, was placed in operation, in May 1939, there has been a back-water effect in the lower 1.5 miles of the Maquoketa River. This back-water has caused the deposition of fine materials in the bed of the tributary stream. These fine materials will no doubt be swept from their temporary position the first time the

Maquoketa reaches a flood stage. Curves showing the size grade distribution of sediments collected from the bottom of this stream are presented in figure 2. The extreme fineness of the sediments taken at the mouth and 0.5 mile above the mouth contrasts markedly with those taken upstream.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 12, NO. 1, PP. 10–30, FIGS. 1–9, TABLES 1–4, APRIL, 1942

SEDIMENTS OF CAPE COD BAY, MASSACHUSETTS

J. L. HOUGH*
University of Chicago, Chicago, Illinois

ABSTRACT

Cape Cod Bay, lying on the Massachusetts coast partly enclosed by Cape Cod, is in a glaciated region of low relief. Coarse sediments generally occur in areas exposed to wave and current action as in shallow water near shore or on shoals, and in the deep channel north of the tip of Cape Cod, which is swept by tidal currents. Fine sediments are restricted to the deeper water in the central portion of the Bay, and to the small, well-protected embayments of the shores.

Most of the sediments are well sorted as compared with other shallow-water marine sediments. Within the Bay, the coarser materials generally have the highest degree of sorting while the finer sediments invariably are more poorly sorted. Fine-grained materials contain a small amount of organic matter and generally are stratified in layers 1 to 2 cm. thick. Sphericity of the pebbles varies but little and in a random manner, but roundness decreases with increasing depth of water.

A previously described hard bottom zone in Massachusetts Bay was traced into Cape Cod Bay. This hard bottom consists of a concentrate of pebbles produced by wave and current erosion of glacial drift on the bottom under present conditions.

The sediments studied are similar to those in Buzzards Bay, Massachusetts Bay and San Francisco Bay, but they differ somewhat from those of the continental shelf, a more exposed environment, and from those of Barataria Bay, a more protected environment.

INTRODUCTION

This study is a part of the program of the Woods Hole Oceanographic Institution relating to the investigation of sediments of the continental shelf and coastal waters of the eastern United States. Field operations were carried on from that institution's base at Woods Hole, Massachusetts, during the Summer of 1935. Laboratory analyses of the sediments were made in the Woods Hole laboratory and in the sedimentation laboratory of the University of Chicago.

The objectives of the study were to collect quantitative data on modern sediments occurring in an environment whose characters are known, to describe the relationships between the sediments and their environment, and to discuss the geological significance of these relationships.

THE PHYSICAL ENVIRONMENT

Cape Cod Bay (fig. 1) lies inside the arm of Cape Cod, on the Massachusetts coast. It is one of the larger and deeper embayments of the coastal waters of the eastern United States.

Geology.—The bedrock of the mainland of Massachusetts, west of Cape Cod Bay, is Dedham granodiorite, a part of a shield of igneous and metamorphic rocks which constitutes the bulk of the New England Lowland. A few deep well borings show that the surface of the crystalline mass extends beneath Cape Cod to the east and south. The bedrock is at or near the surface along the western shore of the Bay north of Plymouth. The other shores of the Bay are formed by thick deposits of glacial drift.

The general shape of the bay was determined largely by glacial deposition on an erosional surface of low relief. The shores of Cape Cod Bay consist of frontal and interlobate deposits which are predominantly outwash material (fig. 2). Since glacial times the bay shores, subject to the most violent erosive action, have undergone relatively little change in shape. Headlands and island shores

* Contribution no. 184, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

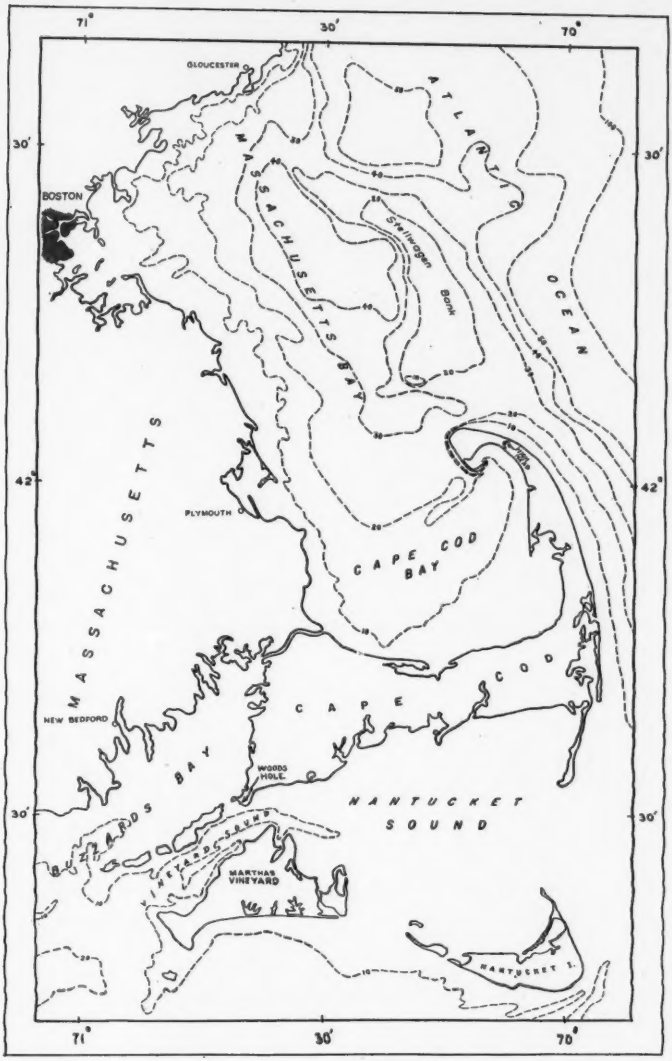

FIG. 1.—Index map showing location of Cape Cod Bay, Massachusetts.

have been cut back considerable distances and many indentations have been reduced in curvature and some have been nearly closed off by deposition of sand and gravel, but the net change in configuration of the shore lines has been small. The greatest change in shoreline has been the formation of the hooked northern end of Cape Cod, north of High Head.

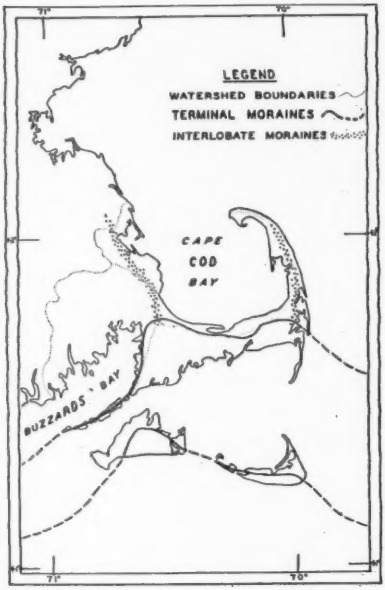

FIG. 2.—Watersheds of Cape Cod Bay and Buzzards Bay, and glacial moraines of the region. (After Woodworth and Wigglesworth.)

When the glacial ice disappeared from southern New England in late Pleistocene time, the sea was perhaps as much as 200 feet below its present level. The bottom of Cape Cod Bay must, therefore, have been exposed to subaerial processes for at least a short time.

Hydrography.—Cape Cod Bay is roughly circular with a diameter of about 22 miles. Its average depth is more than 100 feet and its maximum depth is 220 feet. The bottom topography is shown in figure 3. Considered in detail, the topography is rough and reflects the effects of glaciation. Two well-defined ridges extend across the bay in a northeasterly direction. One of these lies on a line between the Cape Cod Ship Canal and Provincetown, and the other is on a line between Barnstable Harbor and Wellfleet. These may be recessional moraines.

Between the tip of Cape Cod and Stellwagen Bank, to the north (fig. 1), is a channel whose floor reaches a depth of 198 feet. The top of Stellwagen Bank, in its southern part, has an average depth of about 80 feet but a small area on its southwestern corner, opposite Race Point (the northwestern tip of the Cape) reaches a depth of only 57 feet.

Stellwagen Bank, like the arm of the Cape with which it is aligned, is generally considered as an interlobate glacial deposit. After the continental ice sheet disappeared from this area, Massachusetts Bay and a small part of the Cape Cod Bay area may have been occupied by a much-restricted body of water which was nearly or entirely separated from the Atlantic Ocean by the Bank and the Cape. As sea level rose to within 80 feet of its present elevation, two connections with the ocean existed, one to the north of Stellwagen Bank and the other between the Bank and Cape Cod. With continued rise of the sea, Massachusetts Bay was completely connected with the ocean but Cape Cod Bay remained partially enclosed.

The deepest point in Cape Cod Bay, 220 feet, lies at the inner end of the channel between the Cape and Stellwagen Bank. An area comprising several square miles extending from this point toward Plymouth has a depth of more than 160 feet. A well-defined shelf is present in the northwestern part of the bay, as shown by the contours of figure 3. The greater part of the Bay, to the south, has a regularly-sloping bottom with the exception of the two ridges already described.

The bottom configuration of the bay has been made generally more smooth

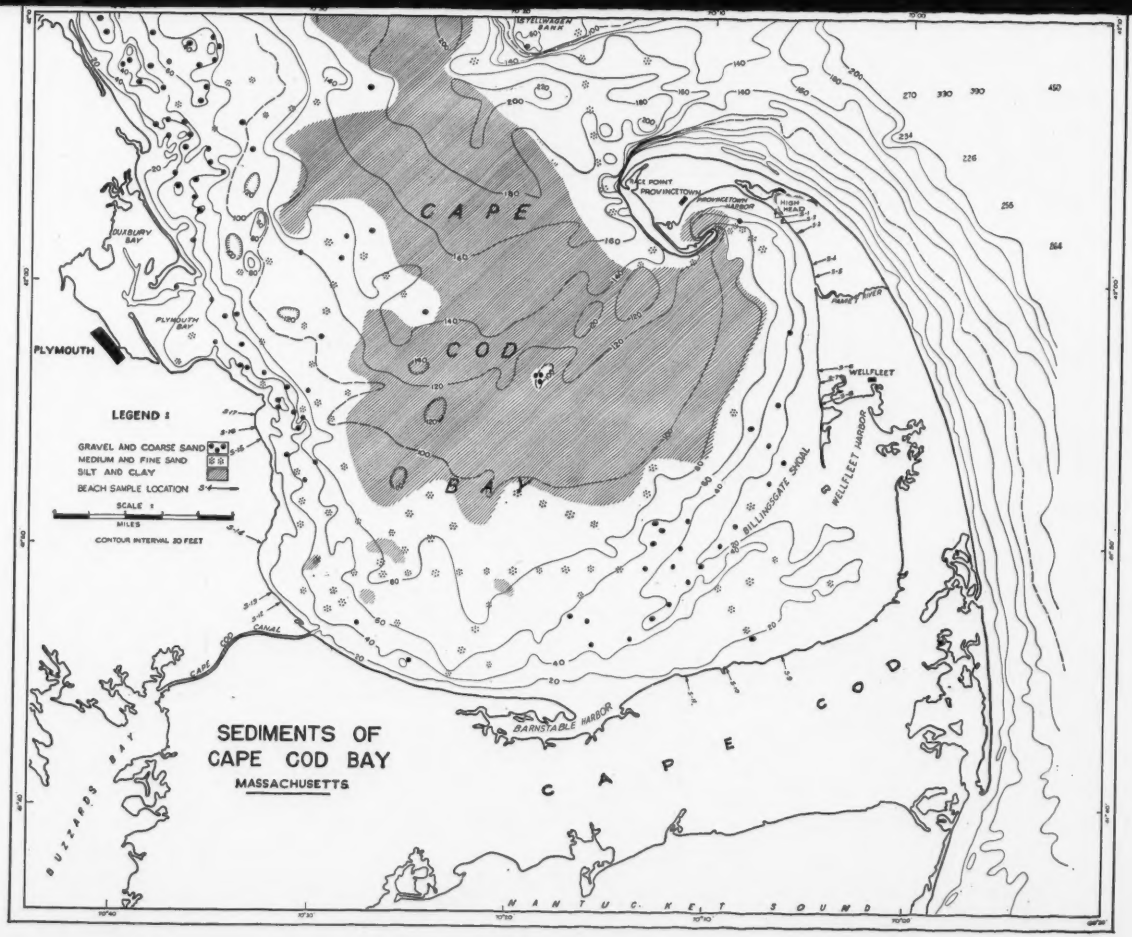
SEDIMENTS OF
CAPE COD BAY
MASSACHUSETTS
LEGEND :
GRAVEL AND COARSE SAND
MEDIUM AND FINE SAND
SILT AND CLAY
BEACH SAMPLE LOCATION
SCALE :
MILES
CONTOUR INTERVAL 20 FEET
CAPE COD BAY
CAPE COD
NANTUCKET SOUND
PLYMOUTH
PLYMOUTH BAY
DUXBURY BAY
BUZZARDS BAY
CAPE COD CANAL
BARNSTABLE HARBOR
PROVINCETOWN HARBOR
HIGH HEAD
WELLFLEET
WELLFLEET HARBOR
BILLINGSGATE SHOAL
ISTFELLWAGEN BANK

FIG. 3

through slight erosion of the higher parts and through deposition of material derived principally from erosion of the shores and above-water portions of the area. The shoal areas, like the beaches on salient points, are protected by coarse concentrates and, therefore, waste slowly. The greatest change in bottom topography has taken place in the deeper, central portion of the bay where accumulation of fine-grained sediment has produced a gently-sloping floor.

The prevailing winds of the region blow from the southeast, but the storm winds generally are northeasterly. Waves generated by the northeasterly storms reach the western shore of Cape Cod Bay although they are damped somewhat by Stellwagen Bank and by dissipation of energy after they pass Cape Cod. Waves generated within the Bay attain considerable size and are important factors in shore erosion. Wave erosion of salient points of the shores, where they are composed of unconsolidated material, has removed a considerable volume of material. Shore erosion on exposed points is resisted, however, by boulder pavements formed by concentration of the abundant coarse particles of the glacial drift.

Wave action on the bottom of the Bay is effective in removing fine material at considerable depths. Outside the areas where bottom currents are the most probable agents of erosion, accumulations of gravel suggest that wave erosion occurs at depths as great as 140 feet. Above the 80-foot contour in the northwestern part of the Bay, a predominance of gravel indicates that wave action is of importance. This area will be discussed in greater detail below.

Littoral currents, generated by the wind and acting in conjunction with waves, play an important role in distribution of sediments. Many bars and spits have been constructed of material derived from headlands and the adjacent bottom.

Bottom currents have not been investigated very thoroughly, but something of their location and strength may be inferred from available information on surface currents and by analogy with other bodies of water. Strong surface currents exist north of the tip of Cape Cod. This fact, and the occurrence of coarse sediment on the bottom in nearly 200 feet of water, indicate that bottom currents are strong also. The vertical range of the tide is 13.6 feet at Plymouth and similar ranges occur at several other points in the Bay. This large range of the tide indicates that a considerable volume of water is moved by tidal action and that tidal currents must be of importance at many localities in the Bay.

Hydrology.—Because of the broad connection between Cape Cod Bay and the ocean, the volume of tidal flow, and the small volume of inflow of fresh water from the land, the salinity of the Bay waters is comparable to that in the adjacent ocean. The oxygen content of the water in the Bay is probably about the same as in the ocean, except where local conditions such as proximity to muds with a high organic content may modify the water adjacent to the bottom.

The average annual precipitation of the area is about 40 inches. The area of land surface draining into the Bay (fig. 2) is comparatively small, comprising 224 square miles, or an area equal to only 36 per cent of the surface area of the Bay, which is 618 square miles.

The soils of the area draining to the Bay generally are sandy and permit rapid infiltration of a large percentage of the rainfall. Slopes in the land area are gentle and the maximum elevation in the watershed is about 325 feet. This is at Manomet Hill near Manomet Point on the western shore. No other point in the area rises above 300 feet. There are numerous lakes and marshes. Drainage is poorly developed and most of the streams flow into estuaries or small, protected embayments rather than directly into the Bay.

As a consequence of the hydrologic conditions described, the quantity of water flowing into Cape Cod Bay from

the land surface is small and the amount of sediment which this water contributes to the open bay must be very small.

METHODS OF STUDY

Field Methods.—Bottom samples were collected from the 40-foot power boat "Asterias," owned by the Woods Hole Oceanographic Institution. Core samples of the fine-grained bottom sediment were taken with a Trask coring tube and samples of coarser material were taken with the Stetson-Iselin sampler and with the Fish Hawk type clamshell snapper (Hough, 1939). The points sampled were located on lines crossing the Bay in various directions, usually between buoys and lighthouses. The usual distance between samples on a line was one mile. Core samples were preserved for laboratory study by wrapping them in sheets of newspaper, while incoherent coarse materials were placed in glass jars.

Beach and cliff samples were collected from the shores of Cape Cod Bay by hand, and each sample is a composite made up of four samples collected within a small area at each locality.[1]

In addition to the beach samples collected for mechanical analysis, two samples of beach pebbles were collected for shape studies. Beach samples A and B. (table 3) were collected from the western edge of the tip of Cape Cod between Race Point and Wood End. Sample A consists of all the particles larger than 4 mm. in diameter over an area about one meter square marked out just above the high tide line on the beach (elevation above mean sea level about 10 feet). Sample B was taken in a similar manner just below the high tide line (elevation about 8 feet).

The beach on the southern shore of the bay between the ship canal and Barnstable Harbor was covered with sand during most of the summer of 1935, but during September, when the beach samples were collected, only pebbles could be found on this shore. Storms in the early part of September had removed the sand.

Laboratory Methods.—Laboratory analyses for mechanical composition were made by the pipette and sieving methods (Krumbein and Pettijohn, 1938).

Shape studies followed Wadell's method (Krumbein and Pettijohn, 1938, pp. 295–299) with certain modifications. Following Wadell, the roundness value is defined as the average radius of curvature of all the corners of a particle. Sphericity is defined as the ratio between the diameter of a circle with an area equal to that of the projection of a plane of the particle to the diameter of the smallest circumscribing circle.

The projection images used for these were obtained by photographing or photostating the pebbles, using appropriate lens combinations to achieve a standard size of about 7 cm. The pebbles were first separated into groups of approximately equal size and placed in their most stable positions on a background of contrasting color.

Statistical Analysis.—The laboratory data were analyzed by the methods described by Trask (1932), involving the use of first quartile, median and third quartile diameters and the calculation of sorting factor ($So. = \sqrt{Q1/Q3}$) and Skewness ($Sk. = Q1 \times Q3/M^2$). The arithmetic means of the sphericity and roundness distributions were calculated by the usual statistical methods.

THE SEDIMENTS OF CAPE COD BAY

General Distribution.—The bottom sediments range from black, fine silts to gravels and boulders. In Cape Cod Bay proper, outside of the smaller embayments such as Wellfleet Harbor and Duxbury Bay, there is a general relationship between size of sediment particles and depth of water, the finer material occurring in the deeper water. The sediments are classified arbitrarily into three types as follows:

I, gravel and coarse sand (median

[1] Four samples were taken to reduce sampling error (Krumbein, 1934). The localities sampled are shown in figure 3.

diameter greater than 0.500 mm.); II, sands of medium and fine grade (median diameter 0.500 to 0.061 mm.); and III, silts and clays (median diameter less than 0.061 mm.).

The areal distribution of these types in Cape Cod Bay is shown in figure 3. In the northwestern part of the Bay, the coarse sediment of type one predominates from the shore outward to a depth of about 80 feet, 5 miles from shore. Southward to a point midway between Plymouth Bay and the Cape Cod Ship Canal this type extends to the 80-foot contour in a narrowing zone which is only 2 miles wide at the southernmost point described. From here southeastward around the southern end of the bay, type one gives way to the intermediate sediment sizes of type two, except in the shallower water, principally above 40 feet. A few areas of type one extend down to the 60-foot contour off Barnstable Harbor and Billingsgate Shoal.

The fine sediment of type three occurs in the central part of the Bay and extends up to the 140-foot contour in the northwestern part, up to about 90 feet in the southern part and above 80 feet in the eastern part along the western slope of the Cape. In the deep water between the northern tip of Cape Cod and Stellwagen Bank, type three sediment is displaced by sands of sediment type two.

On the beaches, sand is by far the most abundant material, though pebbles are present on every shore. During a storm practically all grains of sand size may be removed from the beach, but in a short time sand reappears. Characteristics of the beach sands are discussed in a later section of the report.

Analyses.—The size analyses of the Cape Cod Bay sediments constitute too lengthy a record to be published here, but they may be consulted in the library of the University of Chicago.[2] For an understanding of the study as it is developed in the present paper, this material is not needed since the statistical constants of size distribution are given in tables 1 and 2. Data on properties other than size are given in the following pages.

Statistical Summary of Data.—Statistical constants of the size distribution are given in tables 1 and 2, average sphericity and roundness values are given in table 3, and lithological composition of pebbles is given in table 4. A discussion of these data follows:

[2] Hough, J. L., The sediments of Buzzards Bay and Cape Cod Bay, Massachusetts, Doctor's dissertation, December 1940.

TABLE 1. *Statistical Constants of Bottom Sediments of Cape Cod Bay, Massachusetts*

Sample No.	Latitude	Longitude	Depth in Feet	Statistical Constants					Remarks
				Diameters in mm.			So.	Log Sk.	
				Q1	Med.	Q3			
1	42°05′36″	70°36′18″	30	1.130	1.790	3.190	1.68	+.048	
2	05′48″	34′54″	82	.162	.192	.231	1.19	+.005	
3	06′00″	33′42″	98	—	—	—	—	—	Shells
4	06′18″	32′24″	110	.288	.459	1.350	2.16	+.265	
5	06′30″	31′12″	120	.290	.369	.494	1.30	+.022	
6	06′48″	29′54″	152	.308	.361	.448	1.45	+.025	
7	07′24″	27′18″	174	.498	.815	1.392	1.67	+.017	
8	07′54″	24′42″	180	.021	.051	.086	2.02	−.157	
9	08′24″	22′06″	188	.0905	.122	.179	1.41	+.033	
10	09′00″	19′30″	60	.412	.560	.772	1.37	−.006	
11	09′30″	17′00″	75	.325	.423	.585	1.34	−.024	
12	08′36″	16′45″	150	.164	.234	.378	1.52	+.054	
13	07′36″	16′30″	185	.280	.359	.505	1.34	+.041	
14	06′36″	16′15″	190	.152	.187	.241	1.26	−.020	
15	05′36″	16′00″	175	.172	.244	.344	1.42	−.003	

TABLE 1. *Continued*

Sample No.	Latitude	Longitude	Depth in Feet	Statistical Constants					Remarks
				Diameters in mm.			So.	Log Sk.	
				Q1	Med.	Q3			
16	42°04′39″	70°15′45″	180	.189	.250	.345	1.35	+.019	
17	03′40″	15′30″	140	.224	.279	.345	1.24	−.003	
18	02′42″	15′06″	150	.163	.195	.239	1.17	−.011	
19	00′00″	35′06″	60	—	<.061	—	—	—	Silty clay
20	00′23″	33′40″	93	.121	.164	.334	1.66	+.176	
21	00′45″	32′11″	108	.114	.147	.226	1.41	+.077	
22	01′07″	30′42″	120	.600	.778	1.020	1.31	+.005	
23	01′29″	29′07″	132	.160	.210	.281	1.32	+.008	
24	01′41″	28′26″	135	.464	3.250	18.050	1.97	−.003	
25A	01′55″	27′07″	145	—	—	—	—	—	(1st trial) one pebble
25	01′55″	27′07″	145	.098	.163	.341	1.87	+.099	(2nd trial)
26	02′11″	25′49″	148	.0363	.062	.085	1.53	−.095	
27	02′42″	23′15″	170	.0318	.0365	.0561	2.22	−.236	
28	03′12″	20′36″	180	.0097	.0280	.0434	2.05	−.269	
29	03′42″	18′01″	180	.010	.0341	.060	2.45	−.286	
30	41°54′54″	70°30′30″	65	.096	.125	.170	1.33	+.018	
31	55′52″	30′12″	95	.197	.558	8.450	2.78	−.272	
32	56′52″	29′54″	99	.096	.188	.346	1.90	−.024	
33	57′53″	29′36″	108	1.360	4.050	7.900	2.40	−.184	
34	58′53″	29′18″	115	.129	.212	.317	1.57	−.041	
35	59′53″	29′00″	125	.163	.236	.340	1.69	−.004	
36	42°00′53″	28′42″	135	.390	5.500	21.250	7.39	−.562	
37	41°55′06″	30′30″	66	.116	.138	.180	1.24	+.039	
38	55′23″	29′38″	25	—	>.061	—	—	—	Fine sand
39	55′43″	28′13″	98	.108	.140	.196	1.38	+.034	
40	56′07″	26′48″	100	—	>.061	—	—	—	Fine sand
41	56′38″	25′26″	125	—	<.061	—	—	—	Silt
42	56′58″	24′05″	125	—	<.061	—	—	—	Silt
43	57′23″	22′42″	124	—	<.061	—	—	—	Silt
44	57′48″	21′20″	134	—	<.061	—	—	—	Silt
45	58′13″	19′55″	134	—	<.061	—	—	—	Silt
46	58′40″	18′34″	136	—	<.061	—	—	—	Silt
47	59′02″	17′11″	130	—	<.061	—	—	—	Silt
48	59′31″	15′53″	130	—	<.061	—	—	—	Silt
49	42°00′04″	14′35″	125	—	<.061	—	—	—	Silt
50	00′43″	13′34″	125	.121	.162	.202	1.29	−.032	
51	01′23″	12′58″	150	.112	.139	.178	1.26	−.013	
52	00′58″	27′25″	148	.123	.253	.356	1.70	−.164	
53	00′17″	26′25″	145	—	>.061	—	—	—	Med. sand
54	41°59′36″	25′25″	145	—	>.061	—	—	—	Fine sand
55	58′54″	24′25″	145	—	>.061	—	—	—	Coarse sand
56	58′12″	23′25″	138	—	<.061	—	—	—	Silt
57	56′52″	21′25″	130	—	<.061	—	—	—	Fine silt
58	56′11″	20′25″	124	—	<.061	—	—	—	Fine silt
59	55′29″	19′25″	108	—	<.061	—	—	—	Clay
60	54′47″	18′25″	115	—	<.061	—	—	—	Clay
61	53′23″	16′25″	106	—	<.061	—	—	—	Clay
62	52′01″	14′23″	90	—	>.061	—	—	—	Fine sand, silt
63	50′37″	12′23″	50	.462	.640	.990	1.46	+.057	
64	49′55″	11′23″	37	.340	.650	.990	1.71	−.099	
65	49′13″	10′19″	20	.440	.550	.685	1.25	−.002	
66	48′19″	09′29″	32	.156	.184	.221	1.19	+.008	
67	47′38″	08′41″	26	.159	.187	.235	1.22	+.029	
68	46′53″	07′49″	24	.188	.244	.311	1.28	−.007	
69	46′30″	07′41″	18	.452	.722	.900	1.41	−.107	

TABLE 1. *Continued*

Sample No.	Latitude	Longitude	Depth in Feet	Statistical Constants					Remarks
				Diameters in mm.				Log Sk.	
				Q1	Med.	Q3	So.		
70	41°54′48″	70°29′01″	102	—	>.061	—	—	—	Fine sand
71	54′24″	27′44″	94	—	—	—	—	—	Fine sand, silt
72	54′01″	26′25″	98	—	—	—	—	—	Fine sand, silt
73	53′39″	25′07″	100	—	<.061	—	—	—	Silt
74	53′15″	23′52″	98	—	—	—	—	—	Fine sand, silt
75	53′11″	23′35″	98	—	—	—	—	—	Fine sand, silt
76	52′48″	22′17″	102	—	<.061	—	—	—	Silt
77	52′35″	21′37″	98	—	<.061	—	—	—	Silt
78	52′25″	20′59″	96	—	<.061	—	—	—	Silt
79	52′01″	19′38″	96	—	>.061	—	—	—	Fine sand
80	51′36″	18′18″	93	—	>.061	—	—	—	Fine sand
81	51′13″	16′59″	92	—	>.061	—	—	—	Med. sand
82	50′50″	15′40″	84	—	>.061	—	—	—	Med. fine sand
83	47′46″	28′23″	48	.297	.346	.427	1.20	+.025	
84	48′54″	27′45″	64	.289	.348	.430	1.22	+.008	
85	49′48″	26′48″	78	—	<.061	—	—	—	Fine silt, clay
86	50′28″	25′55″	82	.041	.073	.118	1.70	−.042	
87	51′12″	24′59″	85	—	>.061	—	—	—	Med. sand
88	51′55″	24′04″	85	.041	.071	.110	1.64	−.047	
89	54′02″	21′18″	105	—	<.061	—	—	—	Silt
90	54′46″	20′24″	105	—	<.061	—	—	—	Clay
91	56′13″	18′35″	85	.225	.840	4.450	1.41	+.152	
92	57′01″	17′44″	115	—	<.061	—	—	—	Clay
93	57′47″	16′56″	135	—	<.061	—	—	—	Clay
94	58′40″	16′07″	120	—	<.061	—	—	—	Clay
95	49′20″	26′26″	80	—	>.061	—	—	—	Fine sand
96	49′47″	25′12″	84	—	>.061	—	—	—	Med. sand
97	50′14″	23′59″	80	—	>.061	—	—	—	Med. sand
98	50′43″	22′46″	88	.045	.084	.129	1.69	−.085	
99	49′42″	28′58″	61	.037	.069	.103	1.67	−.095	
100	48′53″	26′23″	82	—	>.061	—	—	—	Fine sand
101	48′55″	25′01″	82	—	>.061	—	—	—	Fine sand
102	48′56″	23′43″	76	.208	.275	.361	1.32	−.002	
103	48′58″	22′28″	88	.044	.076	.101	1.52	−.114	
104	49′00″	21′07″	82	—	>.061	—	—	—	Fine sand
105	49′02″	19′47″	84	.042	.084	.110	1.62	−.183	
106	49′05″	18′28″	79	—	>.061	—	—	—	Med. sand
107	49′06″	17′10″	75	.089	.105	.152	1.31	+.090	
108	49′08″	15′49″	65	.091	.108	.131	1.20	+.009	
109	49′10″	14′26″	59	.116	.140	.197	1.30	+.066	
110	49′11″	13′07″	50	.500	.720	.950	1.38	−.038	
111	49′13″	11′49″	29	.423	.599	.810	1.38	−.019	
112	45′06″	23′00″	55	.089	.102	.113	1.13	−.015	
113	45′59″	22′17″	66	.091	.110	.146	1.27	+.041	
114	46′48″	21′40″	74	.115	.139	.158	1.17	−.029	
115	47′44″	20′59″	80	.064	.095	.110	1.31	−.106	
116	46′11″	15′44″	45	.431	.920	1.780	2.03	−.043	
117	47′07″	16′00″	46	.440	.641	1.700	1.97	+.260	
118	48′05″	16′18″	60	.204	.260	.335	1.28	+.003	
119	52′03″	13′00″	84	—	>.061	—	—	—	Fine sand
120	53′04″	12′47″	95	—	>.061	—	—	—	Fine sand
121	54′01″	12′32″	100	—	<.061	—	—	—	Silt and clay
122	55′00″	12′19″	105	—	<.061	—	—	—	Silt and clay
123	55′59″	12′02″	105	—	<.061	—	—	—	Silt and clay
124	56′59″	11′47″	100	—	<.061	—	—	—	Silt and clay
125	57′58″	11′34″	110	—	<.061	—	—	—	Silt and clay

TABLE 1. *Continued*

Sample No.	Latitude	Longitude	Depth in Feet	Statistical Constants					Remarks
				Diameters in mm.			So.	Log Sk.	
				Q1	Med.	Q3			
126	41°58′56″	70°11′19″	114	—	<.061	—	—	—	Fine sand, silt
127	59′56″	11′06″	115	—	<.061	—	—	—	Fine sand, silt
128	42°00′56″	10′54″	120	—	<.061	—	—	—	Fine sand, silt
129	41°45′36″	14′45″	35	.302	.465	.740	1.57	+.014	
130	46′23″	13′54″	40	—	>.061	—	—	—	Pebbles, sand, shells
131	47′06″	13′00″	37	.183	.249	.318	1.32	−.026	
132	47′47″	12′06″	35	.315	.592	.892	1.68	−.095	
133	48′31″	11′12″	40	.396	.498	.596	1.23	−.022	
134	50′00″	09′27″	12	.432	.554	.695	1.27	−.003	
135	50′41″	08′36″	10	.362	.465	.607	1.29	+.009	
136	51′36″	07′48″	9	.374	.487	.624	1.29	−.007	
137	52′27″	07′00″	7	.495	.719	.864	1.32	−.083	
138	53′14″	06′11″	7	.325	.509	.671	1.43	−.076	
139	53′53″	07′03″	28	.950	1.225	1.700	1.34	−.030	
140	54′32″	07′55″	50	.518	.747	1.197	1.52	+.046	
141	55′11″	08′46″	67	.137	.305	.620	2.13	−.040	
142	56′26″	10′25″	100	.0051	.0195	.049	3.10	−.182	
143	57′46″	12′06″	115	—	<.061	—	—	—	Clay
144	58′42″	13′23″	125	.006	.0235	.055	3.02	−.223	
145	59′57″	15′06″	140	—	<.061	—	—	—	Clay
146	42°00′42″	15′55″	146	.0065	.026	.055	2.91	−.276	
147	01′35″	09′52″	96	—	<.061	—	—	—	Silt
148	01′47″	09′36″	100	—	<.061	—	—	—	Silt and shells
149	01′58″	09′20″	88	—	>.061	—	—	—	Fine sand
150	02′07″	09′05″	67	—	—	—	—	—	Fine sand, silt
151	02′19″	08′49″	70	.092	.146	.830	3.01	+.551	
152	02′29″	08′35″	34	—	>.061	—	—	—	Coarse sand
153	02′11″	08′28″	65	.014	.064	.670	6.91	+.358	
154	01′48″	08′00″	65	.262	.418	.620	1.54	−.030	
155	01′26″	07′32″	58	.165	.436	.780	2.17	−.169	
156	02′32″	09′22″	52	—	<.061	—	—	—	Silt and clay

INTERRELATIONS OF PROPERTIES OF THE SEDIMENT

Before the characteristics of the sediments can be correlated with the factors of their environments, it is necessary to determine which of those characteristics are interdependent.

Median Diameter: Sorting.—Figure 4 shows the relationship between median diameter and sorting factor for all Cape Cod Bay samples analyzed with the exception of the beach samples and those from Provincetown Harbor, an environment which is not typical of the open bay. Most of the coarser sediments are well sorted, 85 per cent of the material coarser than 0.062 mm. having sorting factors less than 1.75, while the finer sediments with median diameters less than 0.062 mm., all have sorting factors greater than 2.00. The same relationship was found in Buzzards Bay sediments (Hough, 1940).

In figure 4, a line was drawn to represent the general trend of distribution of points and this indicates that the degree of sorting becomes slightly better from the larger median diameters down to about 0.15 mm., then becomes markedly poorer as the diameters decrease.

Median Diameter: Skewness.—Figure 5 shows the relationship between median diameter and log of skewness for the same samples as are plotted in figure 4. The line following the general trend of

TABLE 2. *Statistical constants of beach sediments of Cape Cod Bay, Massachusetts*
(Locations of samples are shown in figure 3)

Sample No.	Locality	Statistical constants				
		Diameters in mm.			So.	Log Sk.
		Q1	Med.	Q3		
1	beach	.710	.830	.925	1.142	−.020
2	"	.678	.787	.910	1.158	−.002
3	"	.691	.830	1.005	1.204	+.004
4	"	.451	.542	.658	1.210	+.004
5A	"	.513	.607	.730	1.192	+.007
5B	cliff	.343	.442	.588	1.310	+.019
6	beach	.430	.510	.605	1.184	.000
7A	"	.447	.640	.905	1.428	+.025
7B	cliff	.395	.622	1.000	1.590	+.009
8	beach	.399	.491	.619	1.243	+.009
9	"	.406	.542	.720	1.330	.000
10	"	.351	.428	.561	1.265	+.025
11	"	.408	.628	.860	1.450	−.050
12	"	.478	.570	.682	1.194	.000
13	"	.419	.552	.740	1.328	+.007
14A	"	.383	.481	.602	1.252	.000
14B	cliff	.160	.213	.282	1.328	−.002
14C	"	.649	.908	1.380	1.457	+.035
15	beach	.540	.661	.815	1.228	+.115
16	"	.281	.310	.411	1.208	+.079
17	"	.245	.311	.432	1.327	+.215

distribution of points in this graph indicates that the log of skewness varies from a low negative value in the coarser grades to a very low positive value in the vicinity of median diameter 0.15 mm., then becomes strongly negative as the sediment becomes finer. Whether there is a genetic relationship here is not apparent, but the observed data agree with earlier findings[3] in that the finer sediments tend to become increasingly negatively skewed. Thus it is seen that in both the sorting and skewness relations to median diameter the sediments of the two bays are comparable.

TABLE 3. *Average sphericity and roundness of pebbles of Cape Cod Bay, Massachusetts*

Sample No.	No. of pebbles	Elevation in feet	Average sphericity	Average roundness
Beach A	81	+ 10	.661	.678
Beach B	97	+ 8	.658	.616
1	80	− 30	.707	.506
3	7	− 98	.694	.543
4	96	−110	.683	.503
6	6	−152	.675	.478
7	91	−174	.692	.415

Sorting: Skewness.—The relation between sorting factor and log of skewness was investigated by plotting these two functions in a graph. The result showed that the well sorted samples have an average log of skewness of zero, and the poorly sorted samples are highly skewed, in a negative direction, as would be expected from a consideration of the median: sorting and median: skewness relations.

Median Diameter: Sphericity.—The average sphericity values of the various pebble samples analyzed (table 3) have a small range of variation, from 0.658 to 0.707. No significant correlation between size and sphericity can be established in this narrow range. The relation between size and sphericity of pebbles in an individual sample (Beach B) was investi-

[3] Buzzards Bay sediments, Hough, 1940.

gated, and it was found that the sphericity variation was small and random from one size grade to the next. Both the sphericity and size ranges may have been too small, however, to disclose any relationship between them.

Median Diameter: Roundness.—Roundness was found to be independent of size in a comparison of these properties for individual pebbles of a sample as well as in a comparison of the values for all of the pebbles in all of the bottom samples. Likewise, a comparison of size and roundness of all the pebbles in all of the beach samples showed no correlation between these properties. The independence of size and roundness is unique in this suite of samples, in so far as the writer has been able to determine. Published reports dealing with these properties in other sediments indicate an interrelationship, roundness generally being less in the finer particles.

Sphericity: Roundness.—A comparison of average sphericity with average roundness for the samples studied (table 3) showed no clear interrelationship except that the beach pebbles, which are rounder than the bottom pebbles, are slightly less spherical. Further comparisons were made of these two functions for individual pebbles in one of the beach samples and two of the bottom samples, and no correlation was found. Whether this lack of correlation has any genetic significance is not known.

Rock Type: Shape.—A comparison was made of the sphericity and roundness values of the various rock types in beach sample B, and very little correlation was found between these functions and lithology except that quartz is more spherical

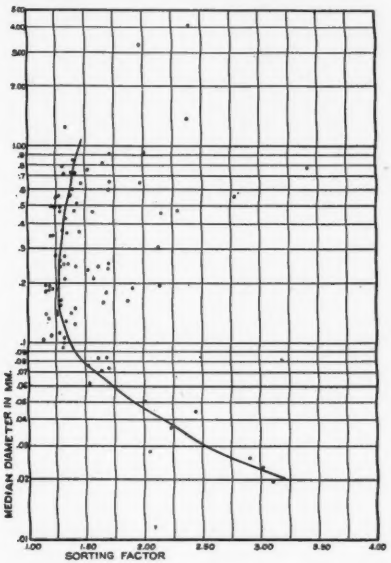

FIG. 4.—Relation between median diameter and sorting factor of Cape Cod Bay sediments.

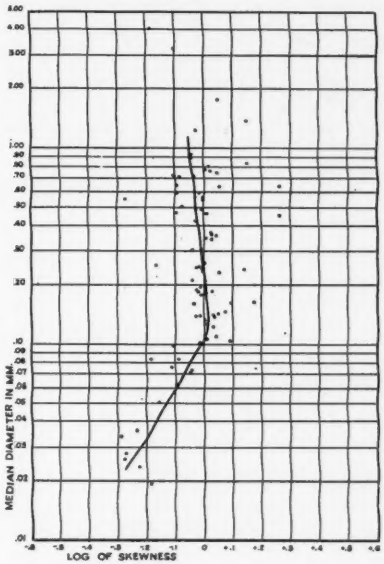

FIG. 5.—Relation between median diameter and log of skewness of Cape Cod Bay sediments.

and better rounded than the average material of the sample. Rock types were tabulated for three samples of beach pebbles collected near the tip of Cape Cod. The types and their average frequency are given in table 4.

TABLE 4. *Lithological composition of beach pebbles, Cape Cod, Massachusetts*

Rock type	Average frequency by number per cent
Granite	30
Diorite and gabbro	13
Basalt	12
Other volcanics	6
Schist	4
Slate	2
Quartzite	5
Vein quartz	22
Sandstone	2
Conglomerate	1
Chert	2
Unidentified	1
Total	100

INTERRELATIONS BETWEEN PROPERTIES OF SEDIMENT AND FACTORS OF ITS ENVIRONMENT

Depth of Water: Median Diameter.—No significant degree of correlation was found between the median diameter of a sample and the depth of water from which it was collected, when all of the data were plotted on a graph. The map, figure 3, indicates, however, that there is a degree of regularity in the distribution of the sediments in relation to their environments. Material within a certain size range is characteristic of a certain depth range within a circumscribed part of the bay. Differences in local conditions apparently are of greater importance than absolute depth in determining the characteristics of the sediment. In general, coarse-grained material may occur at any depth whereas the finest material is restricted to deep water in the open bay and to the protected embayments of the shore.

The fine sediment of type three is generally black when wet, apparently because of the reduction of iron oxides to sulfides as a result of organic decomposition. In the area northwest of Stellwagen Bank, the boundary of the fine sediment is related not to depth of water but to distance from the current-deflecting masses of the Cape and the bank. There are strong tidal flows in this area, and sands of type two are the common sediment.

Depth of Water: Sorting and Skewness.—There is no direct correlation between depth and the constants of sorting and skewness in the suite of samples as a whole. Since the finer-grained sediments are restricted to deeper water, and these are poorly sorted and highly skewed, there is a correlation between depth and the two constants in a part of the samples. A similar relationship was found in Buzzards Bay sediments.

Depth of Water: Sphericity.—The average sphericity of the pebbles shows little variation and there is no significant relationship between sphericity and depth of water. The beach pebbles are only slightly less spherical than any taken from the bottom of the bay.

Depth of Water: Roundness.—In Cape Cod Bay the beach pebbles are better rounded than the pebbles occurring on the bottom of the bay. As a general trend, roundness is less well developed with increase in depth. This is shown by the curve in figure 6 plotted from the data of table 3 in which depth and roundness are compared. Beach pebbles above the high tide line have the highest average degree of roundness, 0.678, while pebbles of the deepest sample analyzed, from 174 feet of water, have the lowest average roundness value, 0.415.

Stratification.—The core samples collected from Cape Cod Bay, though too short to provide any information on character of the sediment in relation to depth of burial, show stratification of the fine-grained deposit. As in Buzzards Bay, the layers generally range from 1 to 2 cm. in thickness and are marked either by differences in grain size or by accumulations of shells in definite horizons. Where shells are the strata-markers,

there generally are no apparent differences in grain size. Accumulation of the shells may have occurred by a process of growth of shell-secreting organisms during times of slight wave action and consequent low turbidity of the water and slow deposition of sediment, followed by burial during times of storm and rapid deposition of sediment.

Properties of the Beach Sediments and Factors of Their Environment.—Schalk (1938) has made a detailed study of the outer beach of Cape Cod which included samples taken from the stretch around the northern tip of the Cape and extending to Long Point, the recurved spit separating Provincetown Harbor from Cape Cod Bay (fig. 3). His conclusions may be summarized as follows: the cliffs of the eastern shore of the cape are the source of sediment forming the northern end of the cape, and the beach sand becomes progressively coarser in the direction of movement from the cliff section, northwestward around Race Point and southeastward to Long Point in Cape Cod Bay. The increase in median diameter is brought about by the removal of the finer grades of sand from the beach to the water offshore. From Race Point to Long Point the median diameter grades from approximately 1.20 to 1.42 mm.

The coarsest sands of the bay beaches occur on the eastern shore opposite Long Point, about one mile southeast of Provincetown Harbor. There is a decrease in median diameter southward along the eastern shore of the bay. Certain features of this shore, particularly the bar that deflects Pamet River to the northward, indicate a northward movement of sediment. This was recognized by Davis (1896). There is, therefore, an increase in median diameter in the direction of transportation of the beach material, corresponding with that found by Schalk in the beach section extending along the outer side of the cape to Long Point.

The beach sand at Corn Hill[4] on the eastern shore (Sample no. 3A, median diameter 0.607 mm.) is coarser than the material in the adjacent cliff (Sample no. 5B, median diameter 0.442 mm.), but the beach sand is better sorted and has a smaller log of skewness. Beach sample 14A, from the western shore, has a median diameter intermediate between those of two samples taken from the adjacent cliff. The beach sample is better sorted and has a lower log of skewness than the cliff samples. At all three of the above localities, the cliffs are being eroded and are contributing sediment to the beach. It is apparent that beach processes are reworking the material and are producing a better sorted, less skewed sediment. It must be remembered that all of the beach and cliff samples are composites, so that the sorting and skewness values are not representative of individual spot samples.

Transportation of Beach Pebbles.—Pebbles and cobbles up to six inches in diameter have been observed on the Wood End-Long Point beach (at the south side of Provincetown Harbor, figure 3) by several writers. This area, generally, is considered as the end of the above-water portion of Cape Cod, so far as beach transportation of sediments is concerned. The question has arisen as to the manner in which the pebbles have reached this location. Woodworth and Wigglesworth (1934) report an observation by Vaughan indicating that the pebbles may be a part of a local deposit of glacial till or outwash which is incorporated in the Cape. Vaughan subsequently has stated that he considered the pebbles of glacio-aqueous origin; that is, brought to their present position by waves or currents from a glacial deposit in the vicinity.[5]

Schalk (1938) has shown that it is possible for the pebbles to have been carried from the eastern shore of the Cape. No pebbles were found by dredging on the off-shore bottoms on the bay side of this region of the cape. Schalk concluded that

[4] Location of beach samples are shown in figure 3.

[5] Vaughan, T. Wayland, personal communication, June 12, 1940.

they remain close to the low tide mark. His presentation is supported by the writer's observation that even at times of moderate wave action pebbles may be heard knocking against each other in the water's edge on the northern beach of Cape Cod. This indicates that pebbles are moved along the beach in this area.

The "Hard Bottom" Zone.—Trowbridge and Shepard (1932) described a hard bottom zone paralleling the shore of Massachusetts Bay and extending southward to Cape Cod Bay. They indicated that the zone might contain either bed rock or large rock fragments, but favored the postulate of the occurrence of bed rock. It was suggested by them that any finer-grained material that previously had covered the zone was either scraped away by the continental ice sheet or washed away at a time of lowered sea level.

The writer (1932), in a discussion of this paper, suggested that the rock bottom zone contains boulders of glacial origin left as a lag concentrate by erosion occurring principally while the sea stood at its present elevation. In Lake Michigan the writer found a concentrate of pebbles which was sufficiently thin in some places to be penetrated by a coring tube which brought up undistrubed glacial till from below the pebbles. Some of the pebbles in the Lake Michigan concentrates showed glacial striae, which indicates that they have not been subjected to any appreciable wear since their deposition from the glacial ice.

Stetson and Schalk (1935, p. 40) reach the conclusion that "in Massachusetts Bay there is a belt of subangular pebbles roughly paralleling the shore which is a lag concentrate formed by the washing out of the finer constituents of fluvioglacial deposits" and stated that "it is obvious that the . . . pebbles have never been on any beach and that they are being little abraded in their present position."

In Cape Cod Bay, the "rock bottom" zone consists of the area occupied by sediments of type one, as previously described for the northwestern part of the bay. Only a small number of samples were collected in the area, but at every sampling station coarse sand or larger sedimentary particles were found. Shape studies of the larger particles indicate that no appreciable rounding of particles has taken place.

It is interesting to compare the data of table 3 with roundness values for the two samples illustrated in figure 2 of Stetson's and Schalk's paper (1935). One of these is a sample from the beach at Cohasset and the other is from the subangular pebble zone of Massachusetts Bay offshore from Cohasset Beach. From enlarged reproductions of these illustrations, the writer determined roundness values which are plotted in figure 6 and labelled "Stetson." They lie close to the line drawn through the writer's data and

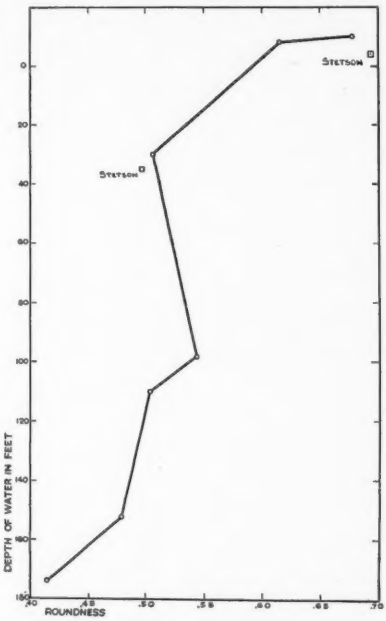

FIG. 6.—Relation between depth of water and roundness of Cape Cod Bay sediments.

conform to the roundness values for samples from similar localities in Cape Cod Bay. The conclusions of Stetson and Schalk in regard to this zone in Massachusetts Bay thus were verified for Cape Cod Bay, and their detailed description of the zone may be considered as applying equally well to the same feature in Cape Cod Bay in their manner of formation.

Abrasion of Pebbles.—It appears that the rigor of processes operating in the bay and the time during which they have operated have not been great enough to alter the sphericity of the pebbles appreciably. Wave action, however, apparently has been competent to round their corners. The greater roundness of the beach and shallow water pebbles may be considered as a result of abrasion rather than selective transportation, because all of the pebbles in the bay have a common source in the glacial deposits and the more highly rounded individuals in the samples having high average roundness values are rounder than any of the individuals in the bottom samples having low average roundness values.

Considering both roundness and sphericity values, it appears that at least the coarser particles of sediment have undergone relatively little abrasion, even in the shallower water where the corners have been rounded to only a barely significant degree. Abrasion of pebbles, therefore, has not been an important source of finer-grained sediment.

In a study of the quantities of material of various sizes which are present in the Bay, the median diameters of all analyzed samples (tables 1 and 2) were plotted on a bar diagram similar to that in figure 9, and the median diameters of all the samples from Buzzards Bay (Hough, 1940, pp. 23–26) were added to the diagram to form figure 9. This combination of data was made in order to present a larger number of samples, and is permissible because the two bays are adjacent bodies of water deriving their sediments from the same source materials. The data for the two areas give similar diagrams when plotted separately. In figure 9, the number of samples having median diameters in each of the size ranges indicated is shown.

There is a relative scarcity of sediment

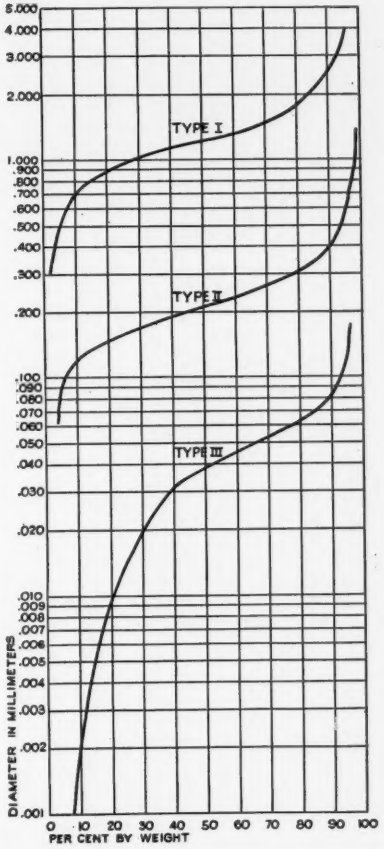

FIG. 7.—Grain-size distribution curves of samples representing the three types of bottom sediment in Cape Cod Bay. (Samples 23, 27 and 139.)

in the size ranges between 2.83 and 2 mm. and between 0.062 and 0.044 mm. A low frequency of material at the same points on the size scale has been observed in

suites of samples from other areas.[6] The significance of the low frequency in the granule sizes is interpreted as follows: above the granule size the sedimentary particles consist largely of rock fragments made up of several mineral grains, while below the granule size the particles consist largely of individual mineral grains. Within the granule size the particles are constituted of only a few mineral grains, perhaps two to four or five. Such a particle is rather unstable because of the few bonds between crystals, and tends to break down rapidly. The coarser material, then, when it is diminished to about 4 mm. in diameter, is broken down rapidly to the size of the individual crystals after which the grains again are reltively resistant to wear.

In the writer's tentative explanation of low frequency in the coarse silt range, consideration is given to the experiments

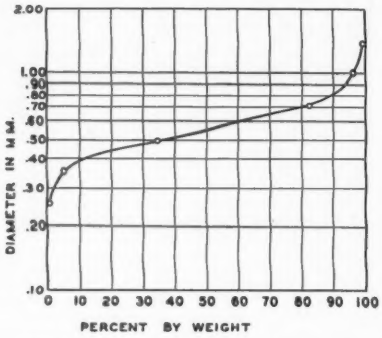

FIG. 8.—Grain-size distribution curve of sample representing the beach sediments of Cape Cod Bay. (Beach sample No. 4.)

of Marshall and others summarized in the *Treatise on Sedimentation* (Twenhofel, et al., 1932, pp. 9–11); these indicate that the work of rock disintegration tends to produce particles of the size of the original mineral grains, while abrasion occurring in water or air does not produce fine sand or coarse silt, but tends to produce rock flour by the breaking off of fragments considerably smaller than the parent grains. Thus a low frequency of material in the coarse silt range might be expected. Grinding in glacial ice may conceivably result in the formation of a somewhat coarser product, so that the frequency of the Cape Cod material is not inconsistent with the deductions from the experiments quoted.

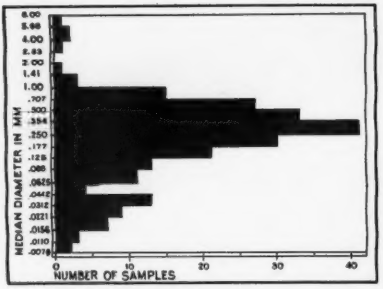

FIG. 9.—Median diameter distribution of Cape Cod Bay and Buzzards Bay sediments.

SUMMARY OF THE CHARACTERISTICS OF CAPE COD BAY SEDIMENTS

Very little sediment has been added to the bay from outside the area since glacial times and the recent sediments are composed of materials derived within the area, principally through erosion of unconsolidated materials of the shores. The nature of the above-water and shallow-water materials subject to erosion and the sorting, wear and redeposition of the materials have determined the characteristics of the recent deposits. Over the bay as a whole, abrasion has been of questionable importance in modification of the size of particles but in the zones of more intense wave action a small amount of rounding with consequent reduction in size has taken place. Organic decomposition has affected the finer-grained sedi-

[6] A scarcity of material in the 4 to 2 mm. diameter range was brought to the writer's attention by Pettijohn (personal communication), and a scarcity of material in the coarse silt range in other suites of samples has been noted by Rittenhouse (personal communication).

ments in particular, giving them a dark color probably through reduction of iron oxides to sulfides.

A representative individual sample from each of the three types of bottom sediment will serve to characterize the mechanical composition of the bottom sediments. The cumulative curves of these are shown in figure 7 and their statistical constants are listed below:

	Median diameter in mm.	Sorting factor	Log of skewness
Type I	1.225	1.33	−0.030
Type II	0.210	1.32	+0.008
Type III	0.0365	2.22	−0.236

A representative beach sample was selected from the Cape Cod Bay suite on the basis of its intermediate position in regard to median diameter, sorting and skewness values. The cumulative curve for this sample is shown in figure 8, and its statistical constants are listed below:

	Median diameter in mm.	Sorting factor	Log of skewness
Beach sample No. 4	0.542	1.21	+0.004

The rock types which constitute the larger sedimentary particles and the mineralogical composition of the finer sediments reflect the known source of the glacial materials in the land area to the north where igneous and metamorphic rocks predominate.

The bulk of the bay sediment probably has been through two sedimentary cycles; during one it was moved from the crystalline rock terrain to the bay area by the continental ice sheet, and during the other, it was removed from the glacial deposits and redistributed by waves and currents to form the recent sediments.

In the bay, coarse-grained particles have tended to remain near their sources or, in the case of the beach materials, to remain within the zone of intense wave action in shallow water, while fine-grained particles have been moved to areas of deeper water.

COMPARISON OF CAPE COD BAY SEDIMENTS WITH THOSE OF OTHER BAYS

Buzzards Bay.—The sediments of the two bays are generally similar in their characteristics and distribution. Comparisons of material in the two areas have been made at various points in the present paper, and reference to the earlier paper on Buzzards Bay (Hough, 1940) will indicate that the summary of properties and relationships of Cape Cod Bay sediments is generally applicable to those of Buzzards Bay sediments.

Massachusetts Bay.—The article of Trowbridge and Shepard (1932) gives complete mechanical analyses of only 20 samples, in the sand range, and partial analyses of 44 others not including the finest sediments. It is impossible, therefore, to compare statistical constants of the various types of sediment in Massachusetts Bay with those for Buzzards Bay and Cape Cod Bay.

Distribution of sediment types in Massachusetts Bay is similar to that in Cape Cod Bay. The types illustrated in the map published by Trowbridge and Shepard were combined to form the three types set up in the present report. The "rocky" zone and the "sand and gravel" zone of Massachusetts Bay, when combined, are comparable to type one sediments of Cape Cod Bay and the zone of such material is continuous from the northwestern shore of Massachusetts Bay to the southwestern part of Cape Cod Bay.

A composite histogram of the 64 samples analyzed by Trowbridge and Shepard shows a low frequency of material in the granule size, 1 to 2 mm., corresponding to that found in the Buzzards Bay and Cape Cod Bay sediments. The possible significance of this low frequency has been discussed above. Trowbridge and Shepard explained this low frequency as being a gap between two sediment loads, one moved by storm waves and the other moved by more gentle waves. The writer has explained it as a result of in-

stability of compound particles made up of only a few mineral grains.

San Francisco Bay.—In San Francisco Bay (Louderback, 1939) there are two types of sediment distribution; one, in which grain size decreases with depth of water and distance from certain elements of the shore lines, and another in which the coarseness increases with depth of water. These distributions are related to the peculiar form of the bay and its relation to waves and tidal currents. The deep, narrow channel connecting the central part of the bay with the Pacific Ocean is swept by strong tidal currents which decrease in intensity toward the margins of the bay. In the shallower water near shore, coarser particles are concentrated near sources in headlands exposed to wave action, while progressively finer material, apparently derived from the headlands by wave erosion, is found in progressively deeper water down to a certain level which is comparatively shallow. Below this depth, the second type of distribution occurs, a progression from finer sediments to coarser ones with increasing depth, and this distribution is brought about by tidal transportation and deposition of material brought to the bay largely by the major tributary streams. This second type of distribution is characteristic of the larger area of the bay by far.

In both Buzzards Bay and Cape Cod Bay, there are localities in shallow water in which the grain size decreases with depth, and which are comparable with the first type of distribution of sediments in San Francisco Bay. Near the mouth of Buzzards Bay and in the area adjacent to the tip of Cape Cod in Cape Cod Bay, there are deep channels in which relatively strong tidal currents flow. The physical environments of these portions of the two bays are comparable with that of the greater part of San Francisco Bay, and the sediment distributions are likewise similar.

The tidal marshes of San Francisco Bay contain the finest-grained sediments that were sampled. Tidal marshes and protected inlets in the Cape Cod area also contain very fine material.

Barataria Bay.—Barataria Bay, on the Gulf Coast, studied by Krumbein and Aberdeen (1937), is comparable to the smaller embayments of the Cape Cod region. Plymouth and Duxbury Bays, on the western shore of Cape Cod Bay, have a similar system of tidal channels in a shallow body of water floored with fine-grained sediment. The sedimentary particles present in Barataria Bay are, on the whole, much smaller than those in Buzzards Bay and Cape Cod Bay. In all three bays, however, there is a consistent relationship between size and sorting; the finer sediments are progressively more poorly sorted. In Barataria Bay, as in the deeper part of San Francisco Bay, and in the deeper channels at the mouths of Buzzards Bay and Cape Cod Bay, the size of sedimentary particles increases with increasing depth. A greater strength of tidal currents is the determining factor in each locality.

Statistical constants of comparable sediment types in Barataria Bay and in Cape Cod Bay are similar, as is shown in the following tabulation:

Sediment type	Location	Median diameter in mm.	Sorting factor	Log of skewness
I	Barataria Bay	0.139	1.18	−0.04
II	Cape Cod Bay	0.210	1.32	+0.008
IV	Barataria Bay	0.040	2.33	−0.39
III	Cape Cod Bay	0.0365	2.22	−0.236

Continental Shelf Sediments.—Sediments of the Continental Shelf, as described by Stetson (1938), generally are coarser in relation to depth than are those of Buzzards Bay and Cape Cod Bay (excluding the lag sediments of the bays), as is consistent with the more exposed nature of the shelf environment. A comparison of sediments of the same median di-

ameter, however, indicates that the constants for sorting and skewness are of the same order of magnitude. For example, samples representative of types one and three sediment in the bays and samples representative of two wide zones on the Continental Shelf off Marthas Vineyard have the following constants:

Location	Median diameter in mm.	Sorting factor	Log of skewness
Cape Cod Bay	0.210	1.32	+0.008
Continental Shelf	0.210	1.35	+0.020
Cape Cod Bay	0.0365	2.22	−0.236
Continental Shelf	0.034	2.82	−0.340

There is a remarkable similarity in the sorting and skewness values of sediments from the two environments, when samples with approximately the same median diameter are compared. This suggests that similar marine processes, when they are of the same rigor (as indicated by the median diameter), produce similar size distributions of the sediment.

The same relationships do not occur in a comparison of the fine-grained sediments of the two bays studied with those of the Baltic (Gripenberg, 1939); the Baltic material is finer-grained and has positive logs of skewness.

GEOLOGIC SIGNIFICANCE OF THE BAY SEDIMENTS

The chances for survival of the sediments of bays like those studied are problemetical. Shallow water marine sediments make up a considerable part of the geological record, but most of them were laid down in extensive inland seas rather than close to the border of a continent. It is likely that sediments similar to those of the bays, deposited in corresponding depths and subject to waves and currents of comparable rigor, have been preserved and it may be of value, therefore, to postulate the types of consolidated rocks which might be formed from the bay sediments.

The fine-grained black sediments of the deeper waters would form stratified shales with a dark color, perhaps with a small quantity of organic matter. They would contain iron sulfide minerals and, in the case of the sediment in the southern part of Buzzards Bay, possibly some glauconite. Flakes of micaceous minerals deposited parallel to the bedding would give a typical shaly parting. Stratification of the deposit would be marked both by differences in grain size and by alignment of fossils. The shells in the deposit apparently have accumulated through a process of growth during times of quiescent wave action and burial when large quantities of sediment were deposited. In the fine-grained sediments the shells are generally small, fragile forms which show little evidence of mechanical wear. Solution taking place within the deposit may remove a considerable part of the shell material, however, before lithification is complete. The well-sorted, clean sands, which contain fragments of shells in some places, may form a typical sterile sandstone if solution of the carbonates is completed before the sand is cemented. Structures such as ripple marks in the shallower deposits would be preserved.

Pebble concentrates of the bays, occurring in as deep as 170 feet of water, might be mistaken for beach deposits in a cursory examination. A study of the roundness of the pebbles would serve, however, to distinguish between the beach and the bottom pebbles.

If the record preserved were fragmentary, the occurrence of muds over the fluvio-glacial sands would appear to represent only a minor stratigraphic break, whereas it actually represents a significant change in conditions of deposition.

ACKNOWLEDGMENT

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THE RELATION BETWEEN THE SIZE OF WAVE-FORMED RIPPLE MARKS, DEPTH OF WATER, AND THE SIZE OF THE GENERATING WAVES

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ABSTRACT

The size of wave-formed ripple marks depends on the depth of water and the size of the generating waves. With waves of a given size, the deeper the water the smaller the ripple marks; with a given depth of water, the smaller the waves, the smaller the size of the ripple marks. Certain tank experiments and field observations are described which led to the above conclusions. Since the wave size and the depth of water are variables, and the ratio between these two variables also varies, it is impossible to determine from the size of fossil ripple marks the depth of water under which they were formed.

Scientific interest in the origin and meaning of ripple marks dates back about a century. Johnson (1919) cites an article published in 1841 by Siau, a French engineer, as among the earlier accounts of ripple marks and mentions the well known soundings by which Siau proved the presence of ripple marks to the depth of about 600 feet. In the same book, Johnson has a chapter on "Minor Shore Forms" in which he devotes 23 pages to the discussion of ripple marks and gives a list of 38 references among which are many well-known names in geology.

The earlier studies regarding ripple marks were centered largely on theories of origin. Later the interest shifted more toward the possibility of making use of fossil ripple marks in determining the conditions under which the sedimentary rocks are formed. Outstanding articles of the latter type are those by Kindle (1917) and Bucher (1919). Kindle, in the introduction to his study, states its purpose in the following words:

> A definite and distinctive type of ripple-mark, always results from current action on sandy bottom, a different type from wave action, and still another type from the direct action of wind on sand. If these different types can be recognized by the geologist in examples of ripple mark, their discrimination will, in many cases, afford important aid in determining the history of formations with which he has to deal.

Bucher's paper, which appeared two years after Kindle's, is an attempt to summarize and apply what had been learned up to 1919 regarding ripple marks.

Of the three classes of ripple marks, those formed by winds, by water currents, and by waves of oscillation, the last is the most difficult to investigate directly because of the variable conditions during formation and the difficulties which attend the making of observations during storms. One of the most important questions regarding wave-formed ripple marks and their meaning is that of the relation existing between the size of ripple marks, the depth of water under which they form, and the size of the generating waves. Regarding this problem, Kindle (1917, pp. 28–29) says, "The relation which the amplitude of wave-made ripple-mark bears to depth is a subject which needs further investigation before any final conclusion can be formulated." After giving the results of some observations which do not seem to be very conclusive, he further says,

> "It is probable that the factors controlling amplitude and height of crest in symmetrical ripple-mark include coarseness of sand, depth of water, and wave amplitude. Much addi-

tional work is needed to determine the relative importance of these factors."

In discussing the same point Bucher (1919, pp. 187–188), says,

"Since the amplitude of the oscillation at the bottom of the water body is a function of the height of the water above, this must bear a direct relation to the wave-length of the ripples. It is not impossible that this relation one day will be utilized for the direct determination of the decrease of the wave-amplitude with depth. At present practically no data comparing amplitude of water waves and wave-length of ripples are available. A collection of such data would represent a distinct contribution to the study of ripples."

Both Kindle (1917, pp. 28–29) and Bucher (1919, pp. 189 and 245) recognize that relations exist between size of wave, depth of water, and size of ripple mark. Kindle evidently took his observations in still water *after* the formation of the ripple marks had been completed. As a result, he observed the ripple marks increasing in size with increasing depth of water and stated that this is the normal condition. Bucher, on purely theoretical grounds, seems to have arrived at an understanding of the correct general relations between depth of water, size of waves, and size of ripple marks but says that the relation is very complex. He apparently did not attempt to check his conclusions by direct experiment and observation.

In an attempt to discover the true interrelation of these three elements, a tank study was made at the University of Oklahoma in the spring of 1941. The tank used was of galvanized sheet iron, 8 feet long, 10 inches wide and 25 inches deep. The waves were produced by a V-shaped plunger whose generating face made an angle of 60 degrees with the water surface. It was given a vertical reciprocating movement by means of a small electric motor connected to a walking beam. The size of the waves was regulated by changing the height of the plunger in relation to the water surface. Measurements of the size of waves, depth of water, and width of ripple mark were made with a yardstick. The speed of the motor was such that the plunger made 70 strokes per minute. This gave a wave length of close to 5 feet regardless of the height of the waves. No attempt was made to experiment with various wave lengths or with different sizes of sand grains as this would have added greatly to the time and expense of the study without affecting results in the fundamental question involved. However, as will be seen later, observations made on lakes of different sizes indicate that the length of waves as well as their height is a factor in determining the size of ripple mark produced. This is probably because of the greater velocity involved in the movement since the velocity of a wave varies directly as the square root of its length.

The bottom of the experimental tank was covered with about 3 inches of sand and enough sand was placed in the end of the tank opposite the plunger to allow the formation of a miniature beach. This beach was necessary in order to take up the energy of the waves and thus prevent the formation of refracted waves which would seriously disturb the experiment. Since each downward stroke of the plunger forced a small amount of water forward with the wave a slight undertow was produced. This did not, however, have sufficient velocity to affect the shape of the ripple marks and they had every appearance of being true symmetrical wave-formed oscillation ripples. Since the adjustment of the sand in the process of beach formation sometimes slightly changed the water level in the tank, measurements of wave height and depth of water were taken at the end of each run. This caused small variations in depth of water and explains some slight lack of uniformity in the various series of water depths and wave heights.

The first series of runs were made by varying the wave height while maintaining a constant depth of water. In the second series, a constant wave height was maintained and the depth of water was

changed with each run. In order to measure the width of the ripple marks accurately, it was necessary to empty the tank between runs. The results are given in the following table:

Water depth in inches	Wave height in inches	Ripples per foot
8¼	1	36
8	1½	17
8	2	12
8	2⅜	11
10½	1¾	24
10½	2	14
10¾	2½	13
7¼	2	10
8	2	12
10½	2	14
10¾	2½	13
11⅞	2½	15

The above figures show that with a given depth of water the size of the wave-formed ripples decreases as the wave height decreases. They also show that with a given height of wave, the size of the ripples becomes less as the water becomes deeper. It will be noted that when the depth was kept constant and the wave height varied the size of ripples decreased faster than the decrease of wave height. This is in agreement with the well-known wave formula according to which the diameter of wave orbit is halved with each increase in depth below the water surface equal to one-ninth of the wave length.

The tank study was both suggested and supplemented by observations of ripple marks on sandy lake bottoms made under various conditions of wind. Such studies were made over a period of several years as opportunity offered and hundreds of measurements of ripple marks were taken. The interpretation of the results of such measurements is difficult because of the number of variable factors involved.

As waves approach a shore, the depth constantly changes and usually becomes less. Often there are several wave systems running at the same time which makes it difficult to determine the exact height of waves to which the existing ripple marks owe their origin; these conditions are complicated by the fact that when ripple marks are once formed a change in the size of waves, unless it is very radical, does not result at once in the formation of a new and different set of ripples. On the other hand, there may be no genetic relation between the height of waves at one time and that of ripples measured in a following calm period, as the ripples may have been made by other waves than those measured. Ripple marks are not nearly so stable, as some writers, beginning with Forel, have stated, and they may change as the waves go down. Large ripple marks formed in shallow water near shore by large waves, will nearly always be wiped out and smaller ripples formed in their places by small waves which reach the shore as the water surface becomes quieter after a storm. Changes, other than decrease in size, are also brought about in ripple marks as the sea becomes quieter but such changes will not be discussed here.

As waves increase in size, it becomes more and more difficult to determine the width of ripple marks being formed and with waves 18 inches or more in height, it is practically impossible. Probably the largest oscillation ripple marks have never been measured as they are formed by large waves in shallow water and are completely changed as the sea goes down. I have often measured oscillation ripples 5 to 8 inches wide in one to two feet of water and have measured what appeared to be true asymmetrical oscillation ripples (1941) up to 20 inches, but these were in the zone of translation waves and may have been caused partly by direct current action.

The figures of the following table were obtained while the generating waves were still running.

My notes contain numerous other records of ripple mark measurements. Some of these were taken in water so turbulent that wave measurement could not be made with exactness. All were taken on

Location	Wave height	Wave length	Water depth	Ripple width
Lake Michigan	4 in.	20 ft.	11 in.	10 in.
"	4 in.	20 ft.	16 in.	5½ in.
"	4 in.	20 ft.	18 in.	5 in.
"	4 in.	20 ft.	22 in.	3¾ in.
"	5 in.	40 ft.	8 in.	8 in.
"	5 in.	40 ft.	18 in.	6 in.
"	11 in.	40 ft.	16 in.	20 in.
Crystal Lake	7 in.	12 ft.	10 in.	6 in.
"	7 in.	12 ft.	11 in.	5 in.
"	7½ in.	12 ft.	13 in.	5 in.
White Lake	5 in.	7 ft.	6 in.	4½ to the foot.
"	5 in.	7 ft.	7 in.	6 to the foot.
"	5 in.	7 ft.	8 in.	5 to the foot.
"	3 in.	5 ft.	6 in.	5 to the foot.
"	3 in.	5 ft.	7 in.	6 to the foot.

uniformly sloping bottoms and are believed to have been formed and maintained by the wave systems which were present at the time the measurements were taken. Some of the notes are as follows:

Lake Michigan, July 23, 1938,—"Some ripple marks close to shore were 12 inches wide. They became narrower as the water deepened until they were 4 inches wide in 2 feet of water."

Lake Michigan, August 1, 1938,—"Waves 10 inches high. In 12 to 15 inches of water, the ripples were 6 to 7 inches wide. As distance from shore increased and water deepened the ripple marks became smaller. At a depth of 26 inches they were only 4 inches wide and at a depth of 48 inches they were one to 2 inches wide."

Fisherman's Cove, White Lake, August 3, 1938,—"On bottom deepening one foot in 7 feet with 2 inch waves the ripple marks were 2 to 3 inches wide near the shore but at a depth of 12 inches were one inch to 1½ inches wide. At a little greater depth they became irregular and then ceased."

Again in the same cove,—"Where the bottom deepened only 3 inches in 10 feet with breakers 3 inches high which became smaller as they approached the shore, the ripples near shore were one inch wide. In 4 to 6 inches of water they were 2 to 3 inches wide. At greater depths they were again narrower. The wide shallow flat used up the energy of the waves and caused them to be smaller as they approached the shore."

Some evidence was obtained by studying the lake bottom in calm weather. As stated before, ripple marks change in size and appearance as the waves go down. However, if the depth of water changes in a very short distance, it is fairly safe to assume that the two different sizes of ripple marks were caused by the same waves.

Silver Lake on the east shore of Lake Michigan is a little over a mile in diameter and has a shallow, sandy terrace extending out several hundred feet from the shore. Large cusps often form on this terrace, and in some cases terminate in subaqueous ridges which extend into the lake in a direction nearly perpendicular to the shoreline. With waves coming in and moving nearly parallel to the axis of such ridges, ripple marks are formed which are wider in the shallow water on the ridges and narrower in the deeper water at the side. Along the side of such a ridge where the water deepened from 3 inches to 6 inches in a distance of 18 inches, the ripples decreased in width from 5 per foot to 8 per foot.

Along the shallow east shore of Lake Michigan, the storm-formed cusps in some cases terminate in subaqueous ridges which turn and become parallel to the shore for some distance. These ridges are usually from about 6 inches to 24

inches high and from a few feet to a hundred feet from shore. As the waves come in, large ripple marks form on the tops of the ridges and smaller ones form in the deeper water nearer shore. For example, with water 7 inches deep on the ridge and waves 5 inches high the ripple width was 6 inches, but 2 feet nearer the shore in 11 inches of water it was only half as great. Again with 6 inches of water on the ridge the ripple marks were 4 inches wide but in 16 inches of water 3 feet to leeward they were 3 inches wide. In comparing the size of ripple marks on the off-shore and in-shore sides of the ridge, it was found that on the off-shore side in 21 inches of water the ripples were 6 inches wide, but in the same depth on the in-shore side, they were 4 inches wide. This was due to a loss of energy suffered by the waves in crossing the ridge.

Examination of the above figures shows that the observations of actual wave-formed ripple marks on the lake bottoms agree with the results obtained from the wave tank study. For example, with a given wave size, the ripple marks become smaller as the water deepens, and with a given depth of water, they decrease in size as the waves become smaller.

Thus, it is evident that the size of fossil ripple marks tells little as to the depth of the water in which the ripple marks were formed. Small ripples may be produced by large waves in deep water or by small waves in shallow water. The largest are formed in shallow water by large waves. Large oscillation ripple marks are not formed in extremely deep water even by the largest waves and extremely large ripples are not formed in shallow water by small waves. However, ripple marks 12 to 15 inches wide are sometimes formed when waves 2 to 3 feet high reach the shore and ripple marks 6 to 8 inches wide are fairly common. It is also probable that large storm waves form equally large ripples at considerable depths. It is thus not safe to assume that ripple marks up to a foot in width indicate extremely shallow water conditions at the time they were formed. It is probable that for each size of sediment there is an upper limit for the size of ripple marks that can form and it is known that true oscillation ripple marks will not form at all in extremely fine sediment. If these generalizations should prove to be true they may be used in the solution of the ripple mark problem.

When waves approach a shore over a sloping bottom, their energy is gradually dissipated in friction. If the loss of energy is slower than the loss of water depth, the ripples formed are larger near shore. If the loss of energy is faster than the loss of depth, the ripples formed are smaller near shore. The former occurs where the slope of the bottom is steep; the latter, where the slope of the bottom is gentle. If the bottom slopes gently and is also uneven, considerable variation in ripple width will occur. The complexity of the problem arises because of the presence of two variables; one, the depth of water, and the other, the wave size and the ratio between these two variables also varies.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 12, NO. 1, PP. 36–50, FIGS. 1–3, TABLES 1–7, APRIL, 1942

THE SEDIMENTS OF LITTLE LONG (HIAWATHA) LAKE, WISCONSIN

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ABSTRACT

The sediments of Little Long (Hiawatha) Lake are described. The lake is surrounded by forest and approximately one-half of the sediments is of organic origin. Water composes approximately between 80 and 90 per cent of the deposits which have a maximum thickness of about 10 feet. Lithification would produce a black carbonaceous or bituminous mudstone which would hardly exceed 2 feet in thickness. The sediments yield from 9 to nearly 12 pounds of oil per ton of dry weight. No stratification was seen in any of the organic-rich, fine-grained sediments.

INTRODUCTION

Little Long Lake is situated in the Northern Highland State Forest, southeastern Winchester Township, northwestern Vilas County, Wisconsin. The name of Little Long Lake has been changed to Hiawatha Lake on government maps. The change does not seem wise as this is a lake well known in scientific literature because of the researches of Doctors E. A. Birge and Chancey Juday. The lake has a length of about one-half mile in a nearly north-south direction and a width of about one-sixth mile. The maximum depth slightly exceeds 60 feet. The bottom deposits of the deeper parts of the lake are composed of a soup-like mixture which the writers have designated *sludge*.

Little Long Lake is surrounded by forest which in most places reaches the edge of the water. In a few places small swamps intervene between open water and the trees. Erosion on the shores is limited because of the protection of the living plants and the accumulations of dead plant debris. The only drainage into the lake is by underground seepage and through swamps on the north end. The outlet on the south end carries the overflow into Little Papoose Lake. The basin of Little Long Lake was formed by deposition of sediments released on melting of ice; a buried block of ice may have been partly responsible. The original bottom of the basin is thought to have been reached in some of the sampling.

The sediments of Little Long Lake were selected for study because of the environmental conditions of complete enclosure by forest, absence of organized drainage into the lake, and because the waters of the lake are the brownest found in any lake in Wisconsin. It was thought that the first two conditions would limit entrance of inorganic sediments and that the organic matter in suspension would produce considerable deposits of finely divided organic sediment.

The general environmental conditions in and about Little Long Lake and the brown character of the water suggest that the water should be dystrophic (low in oxygen and nutrient matter), but Doctor Chancey Juday of the Wisconsin Biological Survey states that determinations made on August 22, 1931, at a depth of 17 meters (about 56 feet) showed 3 parts of oxygen per million. This is a high content for that time of year. These figures indicate that at the time the observations were made the waters were oligotrophic (high oxygen content and little nutrient matter). The general abundance of organic matter in the sediments suggest eutrophic (low oxygen and high nutrient matter) conditions. The highly colored water in the lake suggests antiseptic conditions, at least at times, and thus restriction of consumption of organic matter and use of oxygen. The pH of the surface water approximates 7.

The writers are indebted to the officials of the Wisconsin Biological Survey, par-

ticularly Doctor Chancey Juday, for permission to use the facilities of the laboratories on Trout Lake and for suggestions and advice during field studies. The study of the sediments of Little Long Lake was made possible through a research grant from the Graduate School of the University of Wisconsin by funds provided by the Wisconsin Alumni Research Foundation. This assistance is gratefully acknowledged.

SOURCES OF SEDIMENTS ENTERING LITTLE LONG LAKE

The inorganic sediments of Little Long Lake were probably derived from several sources. Some contributions were made from the atmosphere. These would almost of necessity have been carried long distances and thus would have been very finely divided. It is probable that direct contributions have been made by erosion of the shores, but these were probably small after the establishment of vegetable growth about the shores. Some sand may have floated to the middle at any time a sand beach was exposed. The small surface drainage into the lake through swamp effectively filters any inorganic sediments other than colloids and soluble materials so that only soluble materials and materials of colloidal dimensions may be expected to have been derived from this source. There is probably some subsurface seepage into the lake, but the extent is not known. It seems likely that such waters could carry little other than colloidal and dissolved materials. The surrounding glacial and fluvial glacial materials contain little soluble matter so that it is probable that contributions of materials in solution must always have been small.

The covering of the lake with ice during the winter would permit sands and pebbles to be blown over the surface from shores even by weak winds. Ice must frequently have frozen to the bottom adjacent to the shores and on the breakup in the spring floated to any place in the lake before melting and have dropped any inorganic sediments frozen in the ice on the bottom beneath the places of melting. These conditions made it possible for sands and gravels to become parts of sediments on any part of the lake bottom.

The organic sediments are probably both autochthonous and allochthonous. The water draining through the swamps and mantle of dead plant matter around the lake could not have failed to acquire some organic matter and it is very probable that considerable plant debris must have fallen into the lake from the surrounding trees and smaller plants. Insects are numerous in the present forest at times and it is probable that such has always been so. Some of these must have fallen or been blown into the lake.

Planktonic organisms (algae, diatoms, etc.) dwell in the lake, but algae do not seem to be abundant. Fish and probably other nektonic animals live there and the larvae of several land animals are seasonally present. Benthonic animals seem to be of few kinds. Plants dwell about the shores and on the shallow bottoms. The autochthonous constituents are derived from all of these sources.

Since the establishment of the luxurious plant growth about the lake, it seems likely that the sediments have always been rich in organic matter and have always been black. Before this establishment, it seems likely that inorganic constituents dominated and the sediments had light colors. Basal red sediments in cores from the bottom of the lake are thus considered to represent the early stages of its history before the establishment of much plant growth. The time between the disappearance of the ice and the covering of the surface with plant growth is considered to have been relatively short.

SAMPLING OF THE SEDIMENTS OF LITTLE LONG LAKE

Samples were taken from the bottom of Little Long Lake with the Ekman clam shell sampler and a core sampler designed by the senior author. Determinations of the depths of the sediments covering the

bottom were made by means of a spud sampler. This is a long metal rod upon which annular cups have been constructed. It was loaned to the authors by the Soil Conservation Service of the United States Department of Agriculture.

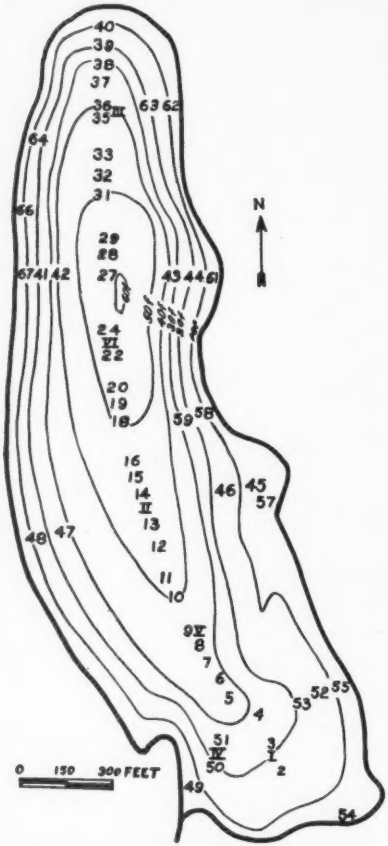

FIG. 1.—Map of Little Long (Hiawatha) Lake. Roman numerals show positions of cores, Arabic numerals the positions of Ekman samples. The contour lines are in feet.

The Ekman sampler obtains sediments from the immediate bottom and it is not correctly known from what depth in the soupy materials of the bottom a sample is derived. The sampler is ordinarily not closed until it has ceased to sink. The core sampler has a length of 6 feet, but due to the friction a core encounters as it penetrates the tube, it is never so long as the tube and ordinarily the length of the core is from 3 to 4 feet. Core samples can be obtained only from fine sediments. Cores can not be obtained from sands unless these are present as thin layers between muds. Furthermore, sediments must have sufficient coherence to remain in the tube as it is pulled from the bottom. Core samples are taken from the base of the point of the tube, at the base of the core after the point has been removed, about the middle of the core and at the top of the core. These are numbered a, b, c, d, from the top down. A total of 70 samples was acquired with the Ekman sampler of which five were taken in connection with the cores and 65 independently of the cores. For one reason or another only 58 Ekman samples were subjected to analysis. The places and depths of acquirement of samples are shown on Arabic numerals on the map of figure 1. Acquirement of samples with the core sampler was attempted at six places. These are shown on the map of figure 1 by Roman numerals. Failure was made at number VI as the sediments would not remain in the tube.

The sampling was done from a raft built over two boats. This method had proved effective on other lakes and was devised by Mr. W. A. Broughton for work on Crystal Lake. The raft was moved over the lake by an outboard motor attached to one of the boats.

GENERAL CHARACTERISTICS OF THE SEDIMENTS

The sediments covering the bottom of Little Long (Hiawatha) Lake consist at the top of an organic-rich sediment termed sludge. Sediments of some parts of the shore and adjacent shallow bottoms are composed of sands and gravels with some larger particles. The sludge has about the consistency of thick soup.

More firm sediments lie beneath the sludge, but even these in some places were found not to have sufficient cohesion to remain in the core sampler as it was pulled from them. The gross color of typical sludge of Little Long Lake is a greenish-brown to black when wet and dark-gray when dry, but microscopic examinations shows it is largely composed of a transparent pale greenish-yellow gel. The sediments immediately beneath the sludge are also black and also largely composed of transparent pale greenish-yellow gel. The blackness in all the sediments is due to organic matter of which some is very finely divided and indeterminate as to origin. Beneath the black sediments at distances of around 6 to 10 feet, the sediments become light colored. A general summary of the sediments on the bottom is as follows:

NEAR-SHORE SEDIMENTS

Most of the east, west, and south shores are covered with boulders and the adjacent lake bottom is composed of sand and fine gravel with fine organic matter and logs and branches. The sands are poorly sorted and the particles of gravel are subangular to angular and up to 4 cm. in diameter. These sediments extend into the lake to depths of 10 to 12 feet. Samples 46, 50, 57, 58, 61, and 70 illustrate these sediments.

Sand with fine to coarse allochthonous organic material (sticks, pieces of bark pine cones, etc.) extends outward from the sediments described in the preceding paragraph to a depth of about 22 feet. The color, both wet and dry, is dark and mostly brown. Samples 45, 48, and 54 are illustrative.

DEEP-WATER SEDIMENTS

SLUDGE, LIGHT GRAY WHEN DRY

Sludge with greenish dark-gray color when wet and light gray when dry extends from the depths of 22 to 60 feet The sludge is composed of a pale greenish-yellow gel filled with finely divided organic matter which is probably both allochthonous and autochthonous in origin, diatom tests, and finely divided inorganic materials. The inorgnaic sediments seem to be largely composed of silt- and clay-size particles of quartz and feldspar. There are occasional grains of sand and visible particles of organic matter. The fine sediments are in a flocculated condition and individual floccules range to 3 mm. in diameter. These sediments are represented in samples 1, 24, 32, 36, 42, 44, 47, 51, 59, and 64.

SLUDGE, DARK-GRAY TO BLACK WHEN DRY

These sediments, derived from the deepest parts of the lake, that is below 60 feet, are black when wet and dark-gray to black when dry. There are no other differences from those of shallower water. Samples 25 to 31 represent these sediments.

CORE SAMPLES

Top and middle samples of the cores, represented by 1a, 1b, 2a, 3a, 3b, 4a, 4b, 5a, and 5c are composed of greenish-gray sediments. Lower samples of the cores, number 1c, 2b, 3c, 4c, and 5 are black when wet and dark-gray to black when dry. All samples have a pale greenish-yellow gel as the most important constituent. Some samples contain sand in visible quantities.

The original bottom of the basin was reached in cores 1, 2, 4, and 5. The samples are composed of pinkish sand and granules. Organic matter is not present, there are no pollen grains, as are abundantly present in higher samples from the cores, and the inorganic sediments are oxidized.

Descriptions of the dry sediments obtained in these cores are as follows:

2a-b. Fine-grained, gray-black silts and clays rich in finely divided organic matter and with pieces of stems, needles of conifers, etc.

2c. Sands ranging from fine to maximum dimension of 2 mm. with some granules and some organic matter. These sands are considered representative of the sediments washed into the lake as the

first plant growth began to be established.

2d. Red silt and clay without organic matter. When these sediments accumulated ice may have surrounded the basin.

4a-c. Fine-grained, gray-black silts and clays rich in finely divided organic matter with pieces of stems, needles of conifers, etc. There is some fine sand.

4d. Sand and granules without organic matter. The sample contains a rounded pebble one inch in diameter. This sample is thought to have been derived from glacial outwash.

5a-c. Sediments like those of 4a-c.

5d. Red silt and clay without organic matter, considered original bottom.

The sands adjacent to the shore are stratified but no stratification of any kind was seen in the organic-rich fine-grained sediments. It is thought that mixing of these sediments by burrowing organisms is largely responsible for the absence of stratification.

THICKNESS OF THE SEDIMENTS IN LITTLE LONG (HIAWATHA) LAKE

Thicknesses of the sediments were determined by means of both the core and the spud sampler. The former was decisive in four cases. Thirty soundings were made with the spud sampler as shown in figure 2. The figures are in feet and give the depth of penetration of the sampler and not the thickness of the sediments although in some cases the bottom of the sediments and the original bottom of the lake were determined. The sampling was begun on the south end of the lake and proceeded from east to west and then from west to east, east to west, etc. in six traverses with five samples to each traverse. Descriptions of the sediments obtained are given below in the order in which the samples were taken.

It is considered probable that original bottom was reached in numbers, 1, 3, 4, 5, 6, 9, 11, 14, 15, 16, 17, 19, 20, 26, and 30. All other soundings do not appear to have penetrated to the bottom of the sediments. Numbers 2, 7, 8, 10, 18, 21, 22, 23, 24, 25, 27, 28, and 29 showed dark organic-rich sediments to the greatest depths penetrated. The real thicknesses at these places is thus somewhat greater than that shown by the penetration of the sampler. It is thought that the total thickness at these places could not have greatly exceeded about 10 feet. Thus, it is considered that the maximum accumula-

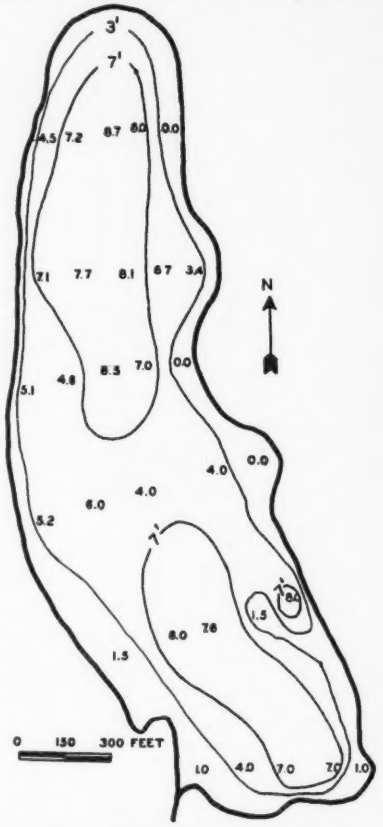

FIG. 2.—Map of Little Long (Hiawatha) Lake showing positions of spud samples. The figures give depths of penetration of the sampler, and the approximate thickness of sediments on the bottom of the lake. The contour lines also indicate thickness of sediments. Dimensions are in feet.

Sample number	Depth of water in feet	Depth of penetration in feet	Description of sediments obtained with the spud sampler.
1	12	1	0–0.7 foot No. sample, 0.7–0.9 foot. Dark-gray to black sediments containing rather coarse sands. 0.9–1 foot. Reddish-yellow sand and clay. This is considered to represent the earliest sediments deposited in the basin.
2	32	7	Greenish-black sediments, no sands, no or few plant fibers. Original bottom not reached.
3	35.5	7	All but the lowest 6 inches consists of greenish-black organic-rich sediments. The lowest 6 inches consists of sediments with somewhat lighter color than those above. These last contain some sand. The original bottom is thought to have been reached.
4	28	4	The entire thickness of penetration consists of dark organic-rich sediments which contain little sand and plant fiber above, but become of lighter color with depth and contain more sand. The sampler is thought to have penetrated close to the original bottom.
5	4.4	0.7	The sediments penetrated consist of gray sands with some organic matter. The lowest inch of penetration has pink color. This is thought to be the original bottom.
6	25.5	1.5	No sample was obtained to the depth of 1.1 feet. The next 3 inches consists of greenish-brown sediments and thence to the bottom of the same kind of sediments with sand. The original bottom is thought to have been nearly reached.
7	40	8	The entire thickness of penetration consists of dark organic-rich sediments without sand. Original bottom was not reached.
8	35.5	7.6	Greenish-brown organic-rich sediments. Original bottom was not reached.
9	25.5	1.5	0–0.7 foot No. sample. 0.7–1.1 feet. Dark organic-rich sediments with sand. 1.1–1.5 feet. Grayish-brown sands with organic matter; color becomes slightly pink at base.
10	21.3	8	Greenish-brown organic-rich sediments which become lighter in color and more silty in lowest 8 inches. Bottom not attained.
11	5		Rocky bottom, probably original bottom.
12	4	4	Greenish-brown, organic-rich sediments. Slightly lighter in color and more silty in lowest 4 inches. Bottom not attained.
13	47	3.7	Like number 12.
14	40	6	0–4.8 feet. Black organic-rich sediments without sand. 4.8–6 feet. Reddish silt or clay, no plant fibre and with coarse sand in lowest foot. Probably original bottom of basin at about 5 feet.
15	28.7	5.2	0–1 feet. No sample. 1–4 feet. Dark organic-rich sediments slightly more silty at 3.3 feet. 4–5.2 feet. Pinkish silt and clay, no sand. Probably original bottom.
16	31	5.1	0–2.6 feet. Dark organic-rich sediments. 2.6 feet to bottom. Pink silt and clay. Probably original bottom.
17	47.5	4.6	0–3.4 feet. Dark organic-rich sediments which become lighter in color and more compact with depth and contains more clay.
18	52.5	8.5	Dark organic-rich sediments to bottom.
19	5	7	0–3.8 feet. Dark organic-rich sediments which become lighter in color and more silty with depth. 3.8 feet to bottom. Pinkish sands, silts, and clays, probably original bottom.
20	19.7		Hard bottom.
21	33.4	3.4	Dark organic-rich sediments which become lighter in color and more silty at about 3 feet. Original bottom not reached.
22	60	6.7	Black organic-rich sediments.
23	64.4	8.1	Black organic-rich sediments.
24	64.4	7.7	Black organic-rich sediments.
25	52.5	7.1	Dark organic-rich sediments which have lighter color and are more silty below 4.3 feet.
26	33.6	4.5	0–3.9 feet. Dark organic rich sediments. 3.9 to base. Gray clays and silts with coarse sands, perhaps original bottom.
27	52.5	7.2	Dark organic-rich sediments which become more compact at 6.2 feet. Not original bottom.
28	55.8	6.7	Like 27.
29	53.5	8	Like 27.
30	44.7		Hard bottom.

tion of sediments in the Little Long Lake basin since the cloaking of the land with vegetation following the melting of the ice approximates a maximum of around 8 to 10 feet with perhaps a slightly greater thickness in the deepest parts of the basin. It will be shown on a later page that 80 to 90 per cent of the sediments is water and that the expulsion of this water in connection with compacting would reduce the maximum thickness to 1 to 2 feet. Assuming that the disappearance of the ice and the cloaking of the land with plant growth took place about 25,000 years ago, this gives a very slow rate of deposition.

WATER CONTENT OF THE SEDIMENTS

The water content of the samples obtained with the Ekman dredge was not determined as this did not seem worth while. The water content of the samples from cores 1, 2, 3, 4, and 5 was determined by the junior author with results as follows:

	1	2	3	4	5
a	89.0%	89.6%	91.5%	90.5%	91.0%
b	87.2	84.2	87.0	87.4	87.8
c	80.0	30.5	85.1	76.9	80.4
d	—	21.6	—	19.0	29.2

The figures show a decrease in water content with depth. The decreases toward the bases of cores 2, 4, and 5 are very rapid. These rapid decreases are due to the penetration of the sampler into the original bottom, or into the sediments deposited prior to the cloaking of the surroundings with vegetation. It is noteworthy that after thousands of years of existence the organic-rich sediments have such high moisture content.

MECHANICAL COMPOSITION OF THE SEDIMENTS

Mechanical analysis of sediments like those in Little Long Lake is attended with considerable uncertainty because of difficulty of elimination of organic matter. This should be eliminated if the analyses are to have any *significance so far as depositional and transportational agencies are concerned.* Several methods of elimination of the organic matter were attempted, but no method was found to be completely successful. Organic matter can always be removed by ignition, but this method fundamentally changes the inorganic components, in many cases changing them to brick-like character. Mechanical analysis of sediments after this treatment would have no significance. Attempts to remove organic matter by means of digestion in concentrated sulphuric acid were not successful. Attempts were made with hydrogen peroxide and although the quantity of organic matter was greatly reduced, it could not be entirely eliminated after more than a month of digestion. It is thought that the digestion led to some concentration of the larger particles of organic matter. Analysis of sediments digested in hydrogen peroxide are given in table 1. The sample numbers show the places of acquirement of the samples. No analyses are given of Ekman samples from which organic matter was not removed. It is thought that mechanical analyses of these samples have little if any sedimentational value and even analyses of the Ekman samples from which the organic matter was partially removed are of very little value. The organic matter present in the form of fragments of leaves, stems, and bark gives an altogether false picture of the physical composition of these sediments if one relies on mechanical analyses for the picture.

There is considerable sameness to many of the samples. The usual grade of maximum quantity is 1/512 or less millimeters in diameter. The only exceptions are samples 25, 26, and 29 and it is thought that the high percentage of grade 1/16 mm. or greater in samples 25 and 26 is due to pieces of plants. The grade of 1/16 mm. is very commonly of larger quantity

TABLE 1. *Mechanical analyses of Ekman samples after partial removal of organic matter by digestion in hydrogen peroxide.*

Sample number	1/16	1/32	1/64	1/128	1/256	1/512
4	1.3	10.1	5.6	10.6	19.0	53.8
6	2.8	7.8	13.4	8.6	18.6	49.0
8	13.9	1.8	7.3	15.7	16.2	45.2
14	7.9	1.2	14.7	16.7	22.6	37.6
16	11.7	2.9	23.3	14.2	13.7	34.8
18	10.1	4.1	8.6	20.3	29.8	28.0
20	3.6	2.5	6.1	17.4	16.6	54.3
22	6.0	1.9	10.8	14.6	12.6	53.4
24	4.9	17.5	5.9	6.5	29.2	36.6
25	50.9	6.3	13.3	7.8	7.9	14.9
26	40.7	15.7	10.5	12.8	4.4	26.7
27	0.8	8.5	14.9	12.3	10.4	53.0
29	1.7	12.0	9.6	37.5	15.0	24.5
33	7.9	3.9	4.3	9.8	23.4	51.4
37	7.4	5.1	12.8	12.7	10.8	51.4
42	13.9	1.0	13.6	14.0	24.4	33.4
44	11.5	14.7	5.0	13.0	9.9	46.0
49	3.1	20.3	1.5	10.3	14.2	50.8
59	4.3	4.1	14.4	13.0	17.5	46.6
64	3.0	9.0	6.7	9.9	17.9	53.8

TABLE 2. *Mechanical analyses of samples from cores.*

Sample number	1/16	1/32	1/64	1/128	1/256	1/512
3	0.8	5.1	20.1	24.6	11.2	39.7
1a	0.9	6.0	10.0	30.2	13.4	39.6
1b	8.3	3.0	44.3	9.7	6.3	28.2
1c	48.3	30.7	6.5	4.8	2.6	6.1
13	2.7	7.7	10.5	22.4	18.2	39.3
2a	8.9	2.8	40.2	3.5	0.5	44.0
2b	6.8	14.8	16.5	25.5	9.0	30.7
2c	63.9	12.0	7.5	4.3	1.2	2.4
2d	19.6	34.2	19.9	11.5	6.3	9.0
35	1.4	12.5	11.9	21.2	16.5	33.3
3a	0.7	4.9	14.1	9.0	18.0	53.2
3b	1.7	2.8	41.0	4.3	24.2	26.0
3c	1.4	11.3	21.3	32.3	2.7	31.1
51	3.0	19.3	9.5	20.2	6.4	41.5
4a	1.7	6.0	15.3	28.5	23.6	25.0
4b	15.3	4.3	18.6	14.7	17.2	30.0
4c	26.0	28.0	20.2	8.7	5.8	11.3
4d	89.4	4.3	1.5	1.1	2.3	0.1
8	0.7	3.6	12.9	23.0	10.2	49.3
5a	0.1	10.4	3.9	32.8	14.4	37.6
5b	3.3	7.4	30.5	7.9	16.9	34.4
5c	3.8	13.3	24.3	18.9	11.0	28.6
5d	10.0	31.0	19.6	10.6	10.5	18.6

than 1/32 or 1/64 mm. This is because this grade also contains all larger particles. The inorganic constituents of all amples, except numbers 25 and 26, ares dominantly of silt- and clay-size and all seem to be largely quartz and feldspar.

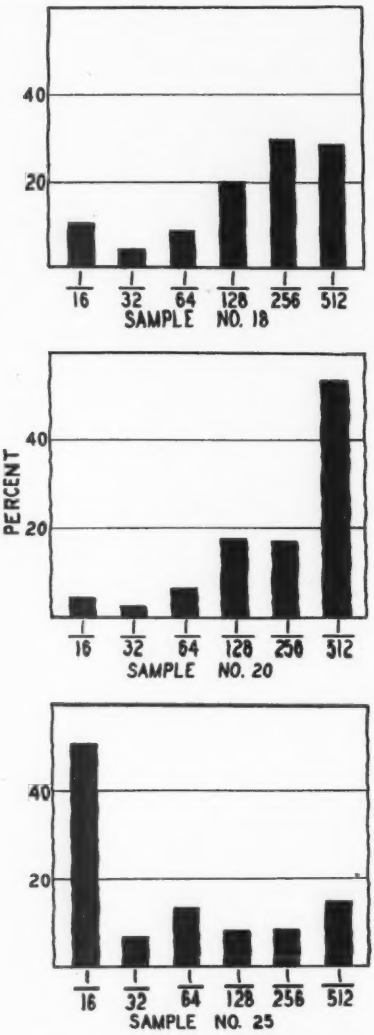

FIG. 3.—Histograms of samples 18, 20, and 25. The organic matter has been partly removed from these samples by digestion in hydrogen peroxide.

Particles of dimensions below 1/32 mm. are thought to have *little depositional or transportational significance as they can remain in suspension in waters of little turbulence. There is little or no assurance that the dimensions of the small particles are those present at the times of deposition.* Some of the particles are tests of diatoms. These have no transportational significance as they grew in the water. A statement that the sediments are dominantly composed of particles of silt and clay size conveys about as much information as the analyses, so far as sedimentational significance is concerned.

Table 2 gives results of the mechanical analysis of the core samples. The sampler is thought to have penetrated the original bottom of the basin, or into sediments deposited before the surroundings became covered with vegetation, in the bottom of cores 2, 4, and 5. Samples of this original bottom are shown in 2d, 4d, and 5d. The particles in these three samples are dominantly in the higher silt and fine sand ranges.

It is thought that curves representing the analyses of these sediments from which no organic matter was removed have little or no value and none is presented. The reader may prepare them, if he so desires, from the fundamental data presented. Histograms of three samples from which the organic matter was partly removed by hydrogen peroxide digestion are shown in figure 3. These are numbers 18, 20, and 25. Number 18 is considered illustrative of numbers 8, 14, 16, 42, 44, and 49. Number 20 is considered illustrative of numbers 4, 6, 12, 22, 24, 27, 29, 33, 37, 49, 59, and 64. Number 25 is representative of number 26. It is not thought that these curves mean a great deal in terms of the factors responsible for the deposition of the sediments or the environments in which the deposition took place *as some of the fine sediments are diatom tests, some of the sediments are organic*

materials, the inorganic sediments were probably flocculated at the times of deposition, and probably some changes have taken place in the sediments since deposition.

ORGANIC CONTENT OF THE SEDIMENTS

The quantity of organic matter in the sediments of Little Long Lake was determined by ignition and in a few cases by the method of reduction in chromic acid. The results are given in table 3. Determinations were made on samples from cores 1, 2, 3, 4, and 5 and from the Ekman samples obtained with the cores. Determinations were made both in the laboratories of the Departments of Chemistry and Geology, those in the Department of Geology by Mr. McKelvey, those in the Department of Chemistry under the direction of Professor V. M. Meloche of that department. The number heading each list is the number of the Ekman sample. The asterisk indicates that the determination was made with the chromic acid reduction method.

It will be noticed that the results obtained by the different analyses do not exactly agree (see table 3). The differences, however, are not sufficiently great to be significant and no greater than should be expected from analyses of different samples. With two exceptions the chromic acid reduction method gave results that are a little higher than those obtained by ignition. It is assumed that most of the loss on ignition resulted from combustion of organic matter, but there was probably a little loss from dehydration of clay minerals and colloidal silica. The extent of loss from this source has not been determined. It should be noted that the total loss from ignition averages about 50 per cent with about half the samples exceeding that figure and about half below. There seems to be a slight decrease in organic matter with depth, but the decrease is not significant. The loss in the sediments derived from deposits made before the cloaking of the region with vegetations or where the materials were derived from the original bottom of the basin probably arises from dehydration.

NITROGEN AND LIGNIN IN THE ORGANIC SEDIMENTS

The determination of nitrogen and lignin apply to the samples from the cores.

TABLE 3. *Organic contents of the sediments of Little Long Lake. The asterisk indicates that the the determination was made by the chromic acid reduction method.*

Core 1		Core 2	
McKelvey	Meloche	McKelvey	Meloche
(3) 44.2%	49.13%	(13) 52.6%	(14) 54.70%
a 46.5	47.87	54.6	55.39
b 49.2	50.96	46.8	51.10
c 32.0	34.32	—	4.34
d —	2.06	—	—
Core 3		**Core 4**	
McKelvey	Meloche	McKelvey	McKelvey*
(35) 50.6%	(36) 55.05%	(51) 43.5%	— %
a 42.0	54.35	66.0	58.70
b 45.9	50.05	37.8	38.93
c 45.4	46.28	34.8	42.40
d —	—	—	0.40
Core 5			
McKelvey	McKelvey*		
(8) 51.80%	— %		
a —	58.50		
b 49.90	59.45		
c 42.80	49.08		
d —	1.50		

TABLE 4. *Nitrogen and lignin in the sediments of Little Long Lake. The number heading each core sample is that of the Ekman sample at the place.*

Number	Lignin	Nitrogen	Crude Protein	Ignition	Lignin/Loss on ignition
3	24.3	0.38	2.38	44.2	54.9
1a	22.4	0.13	0.81	46.5	49.2
1b	27.3	0.16	1.00	49.2	55.4
1c	21.6	0.057	0.36	32.0	67.4
13	29.6	0.29	1.82	52.6	56.2
2a	32.3	0.37	2.32	54.6	59.2
2b	23.3	0.73	4.56	46.8	49.8
35	27.8	0.96	6.00	50.6	53.9
3a	23.3	0.62	3.88	42.0	55.0
3b	21.0	0.13	0.81	45.9	45.7
3c	23.7	0.044	0.27	45.4	52.3
51	21.3	0.19	1.19	43.5	49.0
4a	28.2	0.43	2.68	66.6	42.6
4b	17.7	0.34	2.13	37.6	46.9
4c	13.75	0.36	2.25	34.8	39.5
8	35.6	0.41	2.57	51.8	68.7
5a	—	—	—	—	—
5b	30.6	0.29	1.82	49.9	61.2
5c	17.65	0.15	0.94	42.8	41.3

Determinations were made according to the method of Steiner and Meloche. Results are given in table 4.

The quantity of nitrogen seems to be approximately of the same order of magnitude in most samples but in Ekman sample 35 and core samples 2b and 3a it is exceptionally high.

The lignin content of the organic matter seems to have about the same approximate value in the Ekman and the core samples. It was expected that the percentage of lignin would increase with depth due to microorganic elimination of the less resistant components of the organic matter. The percentage is low in 4c and 5c. This is due to approach to the bottom of the organic sediments. There is no organic matter in samples 2d, 4d, and 5d.

CHEMICAL COMPOSITION OF THE SEDIMENTS

Analyses of the sediments obtained in cores 4 and 5 and Ekman samples 8 and 50 of Little Long Lake were made by Mr. T. H. Walker and of the sediments obtained from core 1 by students of the Department of Chemistry working under the direction of Professor M. B. Meloche. Results are as given in table 5.

The cores show a decrease in loss on ignition with depth except in the case of Ekman sample 50 in which this loss is small. This sample was taken from shallow water near shore and thus would be likely to contain little organic matter. Samples 4d and 5d were deposited in the early history of the basin before plant growth had attained much development in the surroundings and this also seems to apply to 1d. It is thought that the loss on ignition largely represents organic matter. It is obvious that there is no calcium carbonate in the sediments. There may be a little iron carbonate. There could thus have been little loss from decarbonization. The ferric oxide is evidently low and hence there could have been little loss from dehydration. Some of the silica may have contained water which would have been lost on ignition. The silicon dioxide varies somewhat unevenly but, in general, shows an increase with depth.

Taken with the alumina there is a rather consistent increase with depth. It is assumed that this is due to the fact that the alumina and some of the silica are in feldspars. Noteworthy is the high content of silica and alumina in samples 1d, 4d, and 5d, in each of which the silica forms about 75 per cent. The 'd' samples are from sediments deposited in the lake before vegetation clothed the surroundings. A part of the silica is derived from diatom tests and perhaps a part from sponge spicules. The calcium oxide in core 1 is in greater quantity than the magnesium oxide and the sum of the two oxides is 4 per cent or less. In sediments 4 and 5 the calcium oxide is higher in some samples than the magnesium oxide and in others the latter is the greater. The total of the two oxides is usually less than 3 per cent and in most samples less then 2 per cent. The iron seems to be mostly in ferrous form and both the ferric and ferrous iron may be in ferro-magnesium silicates. It would be difficult for free ferric oxide to exist in the organic sediments. Reduction to the ferrous form seems inevitable. The total iron oxides is usually less than 4 per cent except in 1c where it attains 6.57 per cent. There seem to be no trends in the distribution of the iron, calcium and magnesium. It is thought that the iron, calcium, and magnesium are mostly present in the form of silicates. No manganese was found in the sediments. Qualitative determinations showed that phosphorus, sodium, and potassium, are present but the quantities are small.

OIL IN THE SEDIMENTS

The sediments of two Ekman samples, 5 and 50, and those of cores 4 and 5 were tested by Mr. Thomas Walker, a student of the Department, for oil. Tests were made with chloroform and ether. The nature of the oil is not known. Results are given in table 6.

The ether test gave a consistent decrease in quantity with depth. In the test with chloroform the percentage first rose from the top to the middle of the core and then decreased with depth. The 4d and 5d samples which are beneath the organic deposits show very little oil. The average for all the core samples, with 4d and 5d omitted, with chloroform is 0.59 per cent and with ether under the same conditions is 0.49. This yields 10.8 pounds of oil per ton as determined with chloroform and 9.8 pounds as determined with ether.

Some additional determinations for oil were made by Mr. Henry Nelson, using the ether and chloroform extraction methods and also determination by de-

TABLE 5. *Chemical analyses of sediments from cores of Little Long Lake.*

Sample No.	Loss on ignition	SiO_2	Total iron		Al_2O_3	CaO	MgO
1a	47.87	39.60	2.31		6.37	1.05	—
1b	50.96	32.70	3.78		7.03	3.41	—
1c	34.32	47.28	6.57		7.95	1.05	0.66
1d	2.06	75.85	4.02		11.08	2.40	1.20
			FeO	Fe_2O_3			
4a	52.46	34.89	1.22	1.03	9.15	0.42	0.32
4b	40.69	47.51	1.98	0.72	5.77	0.84	1.24
4c	35.30	48.09	2.02	0.93	5.14	0.93	2.02
4d	2.09	80.68	0.59	0.63	10.61	0.51	0.46
5a	54.24	26.51	2.24	0.89	5.15	0.68	0.68
5b	51.14	27.45	3.46	1.03	12.31	0.57	0.63
5c	42.39	39.77	2.98	0.97	12.13	0.49	0.17
5d	3.97	73.45	1.34	0.73	10.24	1.34	0.78
8	54.54	35.40	0.92	0.68	3.44	0.49	0.23
50	5.84	76.97	0.53	0.73	11.11	0.37	0.52

TABLE 6. *Oil in Little Long Lake sediments.*

Sampler number	Chloroform	Ether
4a	0.67%	0.73%
4b	0.78	0.59
4c	0.32	0.31
4d	0.06	0.09
5a	0.54	0.59
5b	0.69	0.37
5c	0.54	0.35
5d	0.08	0.14
5	0.48	0.55
50	0.36	0.33

structive distillation. The determinations were made on composite samples obtained with the Ekman dredge. The method of destructive distillation yielded the largest quantities of oil. Composite samples were used because of insufficiency of material in single samples. The average of oil obtained through ether extraction averaged about 12 pounds per ton, but in one case 27 pounds per ton were obtained. Chloroform extraction yielded an average of about 14 pounds per ton. Extraction by destructive distillation yielded 18 pounds per ton in one case, 20 pounds per ton in another, and 30 pounds per ton in a third. Tests could not always be made with the same sample because of insufficiency of material, but in one case where such was possible, ether extraction yielded 12 pounds per ton, chloroform extraction 17 pounds per ton, and destructive distillation 20 pounds per ton.

BACTERIOLOGY OF THE BOTTOM SEDIMENTS OF LITTLE LONG LAKE

Studies of the bacteria of Little Long Lake were made by Mr. N. E. Rodgers of the Department of Bacteriology of the University of Wisconsin. His samples of the studies were taken from the top, middle, and bottom of the cores and from the Ekman samples collected in connection with the cores. A cubic centimeter was taken in each case from the interior of the cores and from the central portions of the Ekman samples. The total number of aerobic and facultative bacteria were determined by bottle plate counts on a modified sodium caseinate

TABLE 7. *Bacteria in sediments of Little Long Lake.*
Bacteria per c.c. of wet sediments.

	Length of core	Position of sample in core			Ekman sample
		top	middle	bottom	
Station No. 1	2.5 feet				
plate count		2,000	1,100	—	106,000
anaerobes		90	30	—	14,000
Station No. 2 (a, b, and d)	3.33 feet				
plate count		6,000	400	100	98,000
anaerobes		450	90	30	11,000
Station No. 3 (a and b)	—				
plate count		32,000	600	400	72,000
anaerobes		2,000	90	40	11,000

agar. The numbers of anaerobic bacteria were determined by dilution counts in corn liver mash.

The magnitude of the bacterial population at the bottom deposits of Little Long Lake is quite similar to that reported by Henrici and McCoy (1938) for other lakes of this type in the Trout Lake region of northeastern Wisconsin and the progressive decrease in numbers with increasing depth is of the same order as that described by these workers. The accompanying table summarizes the results obtained. The bacterial counts are expressed in numbers per cubic centimeter of the wet deposit.

A qualitative analysis of the bacterial flora was not attempted, but it was noted that without exception chromogenic types were absent, and considerable numbers of aerobic sporeformers were present. This is in accordance with the observations of Henrici and McCoy on similar lakes. Fungi were not detected in any of the samples.

The bacterial counts in all cases of core samples except 3a are quite low. They are not particularly high in the sludge or Ekman samples. There is a rapid decrease in number of bacteria per cubic centimeter with depth.

SUMMARY

(1). The bottom sediments of Little Long (Hiawatha) Lake in depths from about 22 feet to the greatest depth of about 65 feet approximate 50 per cent organic matter of dry weight. Most of the organic matter is of small dimensions and in the form of a transparent pale greenish-yellow gel of which some is assumed to have been precipitated from colloidal organic matter suspended in the water. Pieces of leaves, stems, and bark and the needles of conifers are enmeshed in the gel. Other organic materials in the sediments are tests of diatoms, a few sponge spicules and pollen grains. The inorganic constituents are mostly small particles of quartz and feldspar.

(2). The initial stage of the organic-rich sediments is a black soupy material which the writers have termed sludge. This is over 90% water. The sludge passes downward into more compact sediments which represent former sludge. These sediments are between 76 and 91 per cent water. The organic sediments range in character from the dy to gyttja of Swedish limnologists.

(3). The thickness of organic-rich sediments as they now exist on the bottom of the lake is probably not over 10 feet. These rest on red silt and clay which are believed to have been deposited by melt waters from retreating glaciers. After lithification the organic-rich sediments would hardly exceed 2 feet in thickness. This gives a rate of deposition of not more than a foot in ten to fifteen thousand years.

(4). Lithification of the organic-rich sediments in Little Long Lake would produce a black carbonaceous or bituminous mudstone of which the inorganic constituents would be of clay and silt-size. The rock would contain few to no macroscopic fossils. Identifiable fossil matter would consist of pollen grains, conifer needles, diatom tests, sponge spicules, and pieces of leaves, stems, and bark. The organic-rich sediments seem to be without stratification and the resulting 1 to 2 foot unit of mudstone produced by lithification might show no stratification. On the other hand, some lamination might develop during lithification under pressure and the sediments would form a shale.

(5). The sediments now contain small quantities of oily matter soluble in both chloroform and ether. The resulting rock might also yield considerable oily matter.

(6). The number of bacteria is not large either in the sludge or the organic-rich sediments below the sludge.

(7). Compared to the sediments in Crystal Lake, a very clear water lake in Vilas County, those of Little Long Lake seem to have the same approximate thickness, to contain less organic matter in the sediments beneath the sludge, to contain less organic matter grown on the deep parts of the bottom, to have about

the same bacterial population, and to contain less silica (Twenhofel and Broughton). The high silica content of the sediments of Crystal Lake is thought to be due to tests of diatoms.

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REVIEWS

Cementing Materials in Sandstones and Their Influence on Migration of Oil, by W. A. WALDSCHMIDT, pp. 1839–1879, 1 fig., 10 pls., Bulletin of the American Association of Petroleum Geologists, vol. 25, no. 10, October, (1941).

This work is a study of 111 thin-sections of sandstones from the Rocky Mountain Region. The "sands" range in age from Pennsylvanian to Cretaceous, and all of them represent producing horizons in a number of localities. The thin-sections are described in detail with accompanying plates.

Following the descriptive material are chapters on cementing or binding materials, variations of mineral deposition in geologic section, probable influence of cementing minerals on porosity and permeability, probable influence of cementing minerals on migration and accumulation of oil and gas, probable influence of mineral cements on pressures in oil and gas fields, and conclusions.

The most striking chapter in the paper is that one dealing with the probable influence of cementing minerals on porosity and permeability. The order of precipitation of quartz, dolomite, calcite, and anhydrite cements is determined. The ratio of the number of cementing minerals to the porosity is also determined.

Certain hypotheses are then considered on the relation of cementing minerals to the migration and accumulation of oil and gas. Important and underemphasized is the chapter dealing with the influence of mineral cements on pressures in producing "sands" in oil and gas fields.

The work is illustrative of the rapidly increasing importance of sedimentary petrology in petroleum exploration and petroleum engineering.

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Rip Currents: A Process of Geological Importance, by F. P. SHEPARD, K. O. EMERY and E. C. LAFOND, Jour. Geology, vol. XLIX, no. 4 (1941), pp. 337–369.

Heretofore, the general conception has been that the cumulative landward movement of the surface water along beaches where large waves break was compensated for by a return flow beneath the surface. The authors of this article, however, contend that the return flow takes the form of a seaward moving lane of water at or near the surface and normal to the beach. They have proposed the name "rip current" for this return flow of water. A rip current is ordinarily fed by waters moving along shore from each side.

The authors list six surface manifestations which will serve as criteria for the recognition of rip currents. They are as follows: 1. Sediment-laden water; 2. Green water; 3. Foam belts; 4. Agitated water; 5. Gap in advancing waves; 6. Seaward movement of floating objects.

A description of rip currents is presented which includes a discussion of the origin, width, outward extent, and nature of rip currents; their relation to shoreline configurations and to the channels in the underlying sand which they erode.

The relationship of rip currents to waves, currents, winds, tides and to cut and fill of beaches is considered. Dimensions range from 50 to 100 feet wide in the feeding areas and to 500 feet in width at the head. Velocities are known to be as great as two miles per hour.

The authors conclude that rip currents are important transporting and sorting agents of sediments, that they erode channels near the shores to the depth of a few feet, and that existing evidence is not sufficient to connect the formation of submarine canyons with rip currents. They are a considerable source of danger to bathers.

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Ionic Effects on the Rate of Settling of Fine-grained Sediments, by L. R. DREVES-KRACHT and G. A. THIEL. Am. Jour. of Sci., vol. 239, 1941, pp. 689–700.

The authors of this paper studied the settling rates of 10 fine-grained sedimentary materials suspended in solutions of sodium chloride, potassium chloride, magnesium chloride and distilled water. The concentrations ranged from molar to .01 molar. The various cations in solution with the same molarity were rated with respect to their power of coagulation of fine-grained sediments in order as follows: $Na^+ < K^+ < Mg^+$. Potassium is only slightly better than sodium, but magnesium is very much better than either of the two. The experiments indicated that for the cations used there is a limit to coagulating action which is in the neighborhood of molar concentration; also, with varying concentrations of the same cation a critical concentration in the region of M/10 was found, as below this concentration the coagulation decreases very rapidly.

Variations in settling velocity among different materials in the same suspension medium are explained by the authors on the basis of varying grain size, shape, and uniformity rather than on the basis of particle composition. They state that the "mineral composition of a fine-grained sediment apparently has little effect on the rate of coagulation." In view of the differences of results obtained for such substances as kaolinite, illite clay, fireclay, and bentonite it seems difficult to accept this generalization. Before acceptance of this generalization as to rates of settling of various sediments, it would seem desirable to have detailed data respecting size relations, physical characteristics and chemical and mineralogical compositions of the material studied. The data which the authors have presented should not be considered to indicate more than probable trends.

The more rapid the rate of settling the greater was the thickness of sediment obtained on the bottoms of the containers. This resulted because of water becoming trapped during deposition, and failure of particles to orient themselves to produce the most compact packing. The range in thickness for the same quantities of sediments varied with the molarity and the cations. The flocculates made with the divalent cations of magnesium do not pack as closely as the smaller flocculates made by the univalent cations of sodium and potassium. The deposits were without stratification.

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Gravity Coring Instrument and Mechanics of Sediment Coring, by K. O. EMERY and R. S. DIETZ, Bull. Geol. Soc. Am., vol. 52, 1941, pp. 1685–1714.

This paper describes an inexpensive coring device, and also suggests principles for the interpretation of cores taken from ocean floor sediments.

The core sampler is constructed chiefly of standard plumbing materials, and has a core-tube lining of celluloid, and an efficient core retainer consisting of strips of celluloid.

The authors' experiments on land and in taking cores from the Pacific Ocean floor indicate that all sedimentary layers penetrated are present in a core, but that each layer is thinned during penetration. In the case of sediments which have a uniform water content, the thinning is greater with depth. Most sediments, however, exhibit a decrease in water content with depth and thus an increase in viscosity; the increase in viscosity is often so nearly equal to the increase in friction between a growing core and the inner walls of the core-tube that thinning is no greater at depth than near the surface.

The instrument has been used successfully to depths as great as 12,200 feet. Cores of fine grained sediments up to 16 feet 9 inches in length have been obtained. Sand was found difficult to core.

Core-length varied from 40 to 70 per cent of the distance of penetration. Previous estimates of the actual thicknesses of sedimentary layers on ocean floors are suggested to have been too small because of a disregard for core shortening.

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